IOP Conf. Series: Materials Science and Engineering **431** (2018) 112011 doi:10.1088/1757-899X/431/11/112011

Numerical Analysis of an Embankment Resting on a Combined Mass Stabilization and Lime Columns in Clayey Soil

M H Mehrabi [1], Zainah Ibrahim [1], S S Ghodsi [1] and Meldi Suhatril [1]

[1] Department of Civil Engineering, University of Malaya, Kuala Lumpur, Malaysia.

Abstract. One of the techniques to support embankments is to use a deep mixing method with the addition of structures in many countries. The design has some measurable criteria such as analyses of settlement and stability, even though deep mixed materials are changeable. The primary emphasis of this research is on stability of embankments supported on columns installed by the deep mixing method. Several numerical analyses about the wet method and the dry method have been done in this paper; the dry method includes lower water content of improved soil, lower binder quantity and ordinarily much more strength, while in the wet method it is easier to produce homogeneous columns. Column supported embankments are constructed over soft ground to speed up construction, enhance stability of the embankment, minimize total and differential settlements, and protect adjacent resources. The columns should be durable and stronger than the existing site soil, and if correctly designed, they can impede immoderate movement of the embankment.

1. Introduction

To support embankments and corresponding structures, there have been extensive calculations and data analysis carried out on the application of lime cement columns (LC) and deep mixing method columns (DMM). Deep mixing (DM) columns, like lime columns, have a variety of installation methods and technologies, almost all of which are privately owned.

Data about deep-mixed materials and high strength and stiffness entropy are encountered by unlimited compression tests. Research [1] indicates that the unconfined compressive strength of deep mixed materials shown by (qu), increases with an increase in mixing competency, increasing the quantity of stabiliser, curing temperature, longer curing time, lower organic content of the soil and lower water content of the mixture. As the water content of the mixture rises, the mixing competency increases. Therefore, if less water is used in the clays, the mixture will be stronger. Conversely, in mixed materials such as water and cement, higher water content can give more stability.

A research study aimed at the edge stability of embankments incorporates lime-cement columns, and integrates moment capacity into a limit equilibrium analysis with a non-circular shear surface. The study has solved the limiting horizontal force penetrating through the shear surface that could be carried by columns based on many probable failure implements [2].

Kivelo extends equations for the failure modes; however, there is some obstacle to their application to a slope stability analysis [2]. The presence of columns affects the place of the critical failure surface, thus the equations should be inserted into a computer program for the critical failure surface. The formulas determine a horizontal force placed at the point of the failure surface. It is necessary to integrate the horizontal constituent of the resisting force through the shear surface for exorbitant inclinations of the failure surface. The failures occur due to the bending failure of the suitable bending capacity for columns, and there is some doubt about the bending capacity of DM columns. Kivelo suggests a method for the evaluation of the bending capacity of columns, which relies upon the plasticised area of the column, but he does not describe how to find the area.

The engineering properties of soils are fixed by the DMM, which are affected by several factors such as water, organic contents of the soil, clay, ratios, the type and amount of binder materials. All the parameters affect the strength of soils. Through a reasonable level of accuracy and based on the in-situ characteristics of the soil it is not possible to estimate the strength that will come up from summing of a specific amount of element to a given soil [3].

There are different opinions about the adapted strength cover for DMM for application in the analyses of stability of column-supported embankments. Broms proposes the application of total stress friction angles between 25 and 30 degrees for DMM [4]. Since no unique agreement on strength categories of these materials has been achieved, it is mostly common to use a suitable strength for design. This research focuses on the simulator behaviour of an embankment built on normally consolidated soft soil reinforced with deep mixing columns. The numerical results are evaluated in terms of settlements, increments in vertical effective stresses and excess pore pressures. Firstly, the effectiveness of the use of deep mixing columns is studied. Subsequently, a parametric analysis is performed to study the influence on the soil-columns system of the replacement ratio (columns' spacing) and the deformability of the embankment and columns.

2. Finite element model for embankment prediction

Finite element analysis using Plaxis [5] 2D is carried out for the prediction. Figure1 shows the flow chart of PLAXIS software analysis.

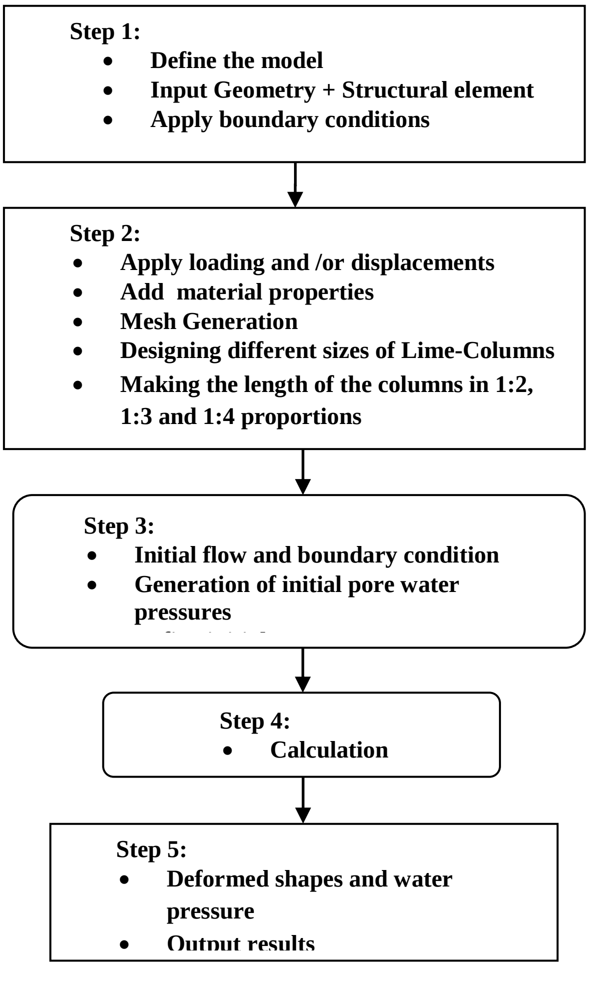


Figure 1. Program flow chart of PLAXIS analysis.

In Plaxis, there are six different material models which vary in terms of the accuracy of the presentation of the mechanical manner of soils. The design for every model defines the relation between strain and stress in the material. The Mohr Coulomb Model is used in this research.

The Mohr Coulomb model has five parameters: Young's modulus (E), Poisson's ratio (ν), friction angle (φ), cohesion (c), and dilatancy angle (ψ). All of these parameters can be obtained in fundamental tests of soil samples. The fundamental stiffness modulus that is employed in Plaxis is Young's modulus (E). Exclusive concentration should be taken to the stiffness parameter during a calculation because many of geotechnical materials show a non linear behaviour. The Mohr Coulomb model employs a fixed stiffness parameter under the whole calculation. Soils do not have a fixed stiffness in the real world. Developing with depth, the stiffness is mainly dependent on the levels of strain and stress to the edge of the embankment (displacements settled just in the linear ways). The dimensions of columns, spacing and the overall foundation dimensions were exemplary values which are used in engineering practice. The model dimensions are given in Table 1.

Table 1. Column dimensions proportion

	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6		Model 7
						L[1]	S[2]	
Column length-proportion	1:0	1:5	1:6	1:4	1:3	16	7.5	-

[1]Long, [2]short

The embankment crest width is 11 metres, the height is 2 metres, and the gradient of side slope is 1.0 on both sides. The ground water table was assumed at the ground surface and the clear spacing between adjacent columns was set at 1.3 metres. The analysis model is shown in Figure 2.

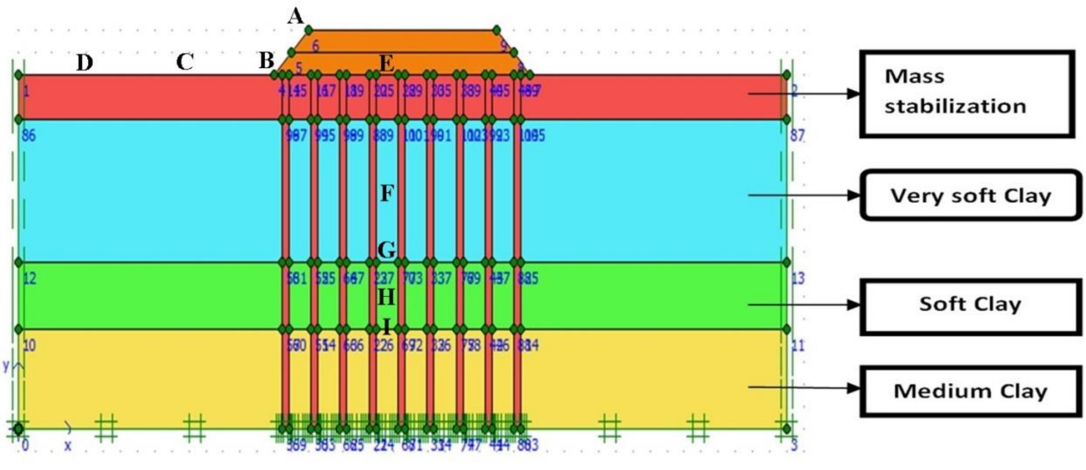


Figure 2. Finite element model of lime columns supported an embankment.

The maximum settlement for model 1 is at the centre of the embankment which is 17mm. According to Meyerhof theory it is acceptable because the tolerable settlement should be less than 25 mm. As the embankment construction is completed the rate of settlement reaches a maximum and then decreases with time and noted that the excess pore pressure increases with the depth from the ground surface. The volume of used lime in the columns and in the mass stabilisation base is 181 m3, furthermore the differential settlement is 7mm. The variations in the vertical displacements and pore water pressure with respect to time are shown in Figures 3 and 4.

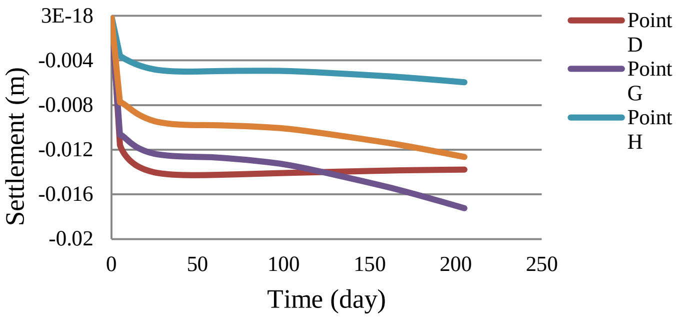


Figure 3. Variation in the vertical settlements at points D,G and H

The excess pore pressure increases with the depth from the ground surface. It is shown beyond doubt that settlement starts instantly during the construction and continues eventually. As the embankment construction is completed the rate of settlement reaches a maximum and then decreases with time. It is assumed that the excess pore pressure included by the installation of columns has decreased before the construction of the embankment. Time to reach 1kpa for point F, G and H are 334, 280 and 290 days respectively.

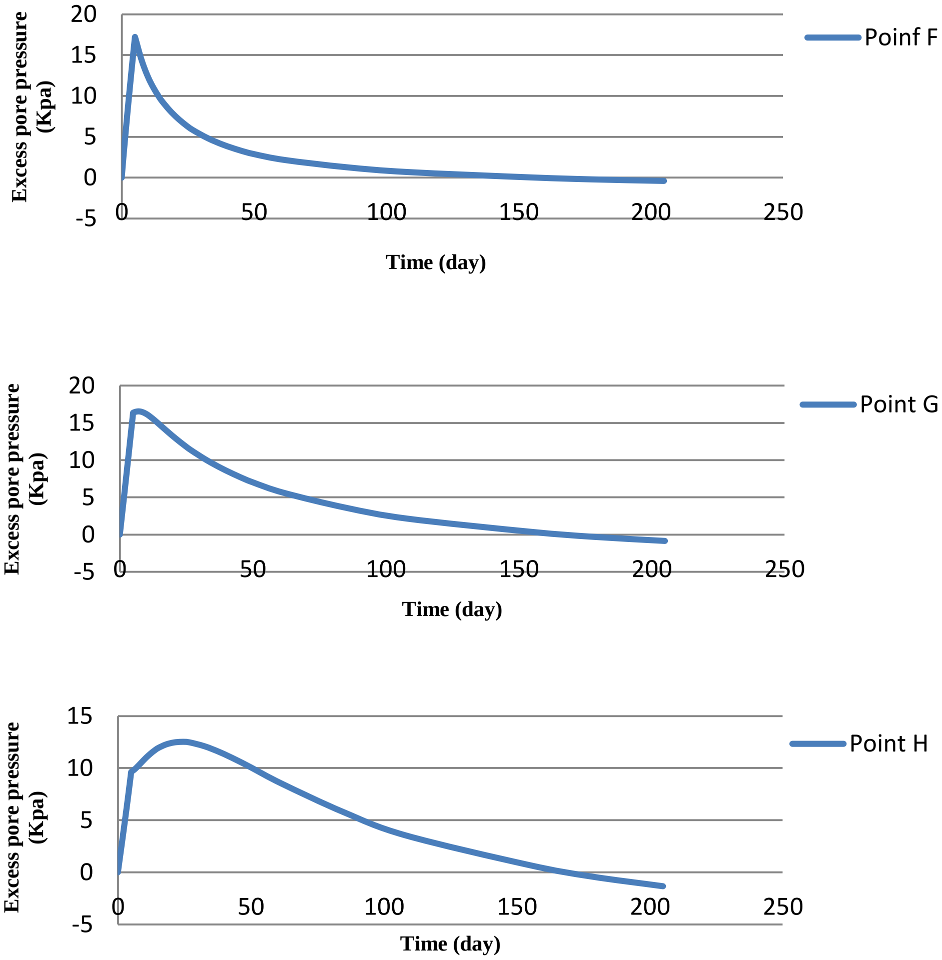


Figure 4. Variation in the pore water pressure at points F,G and H.

IOP Conf. Series: Materials Science and Engineering **431** (2018) 112011 doi:10.1088/1757-899X/431/11/112011

In model 2, the maximum settlement is at the centre of the embankment which is 19mm. It is acceptable because it is less than 25 mm. The volume of used lime in the columns and in the mass stabilisation base is 81 m3, also the differential settlement is 8mm. Time to reach full primary consolidation for all cases is 205 days that is 2kpa. The deformed shape of the embankment after 200 days is shown in Figure 5.

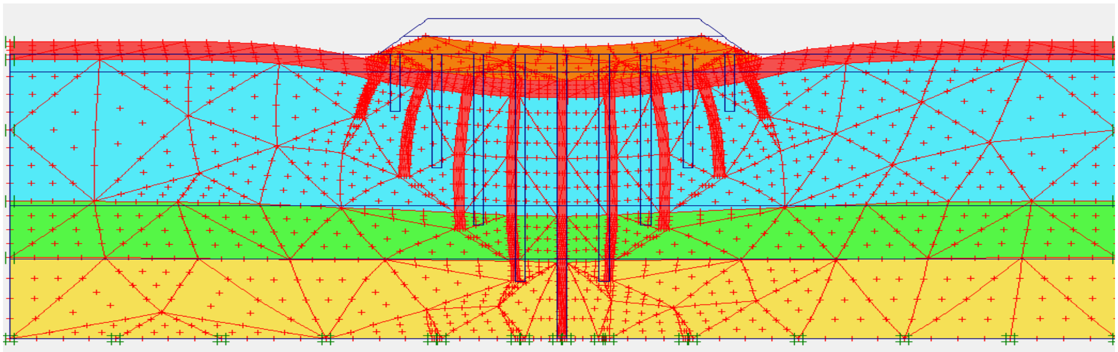
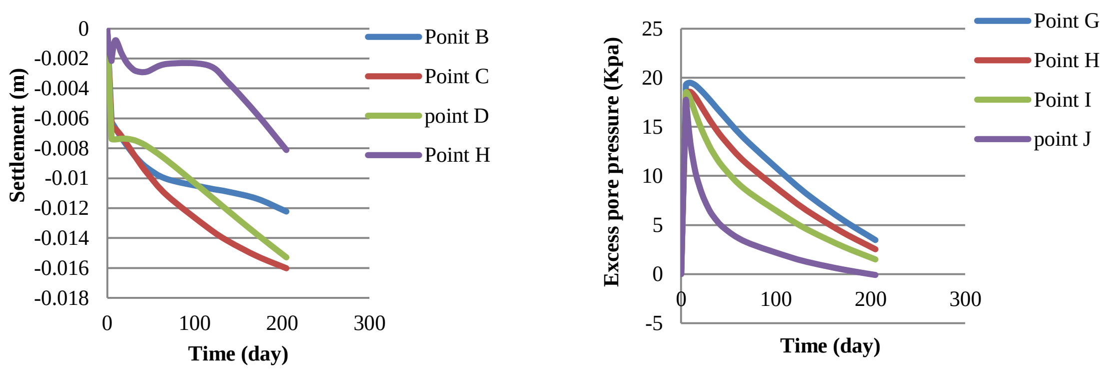
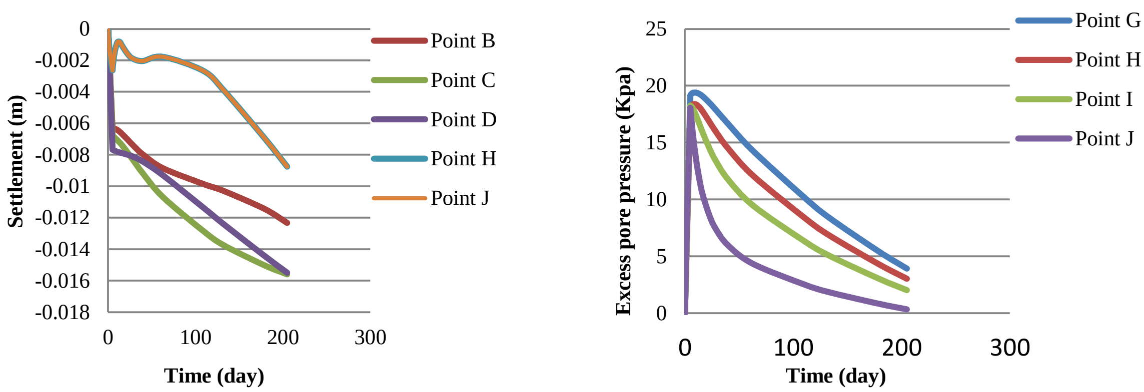


Figure 5. Deformed embankment after 200 days (Model 2)

Figure 6 depicts two aspects of the results: the left panel shows the settlement vs days, while the right panel illustrates the excess pore pressure and time.

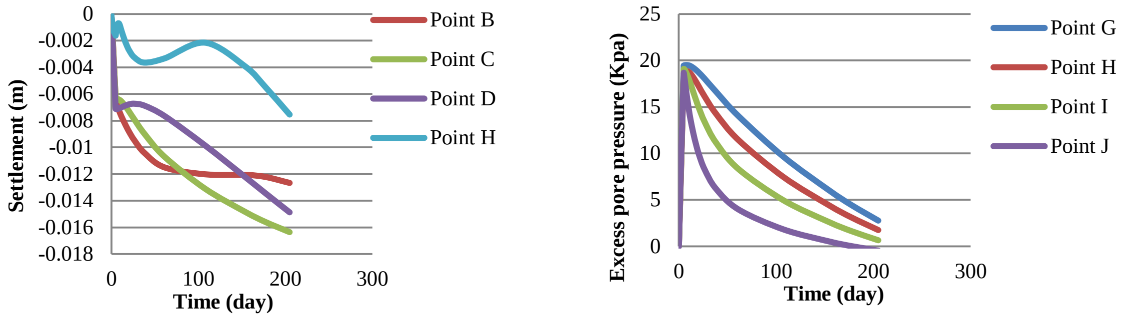


Model 2

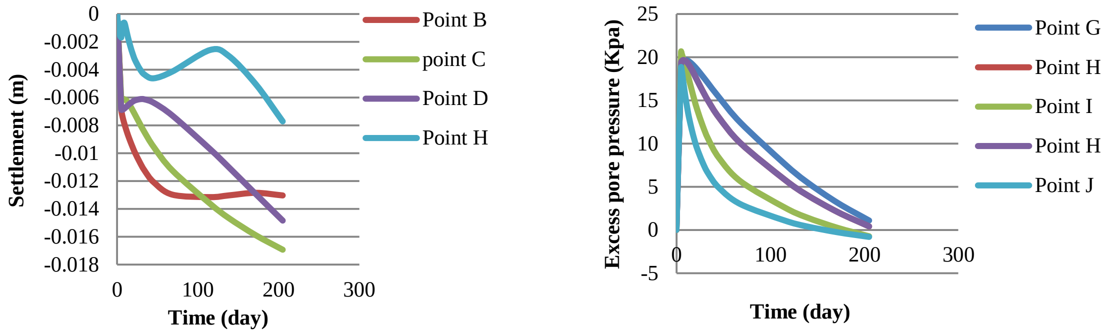


Model 3

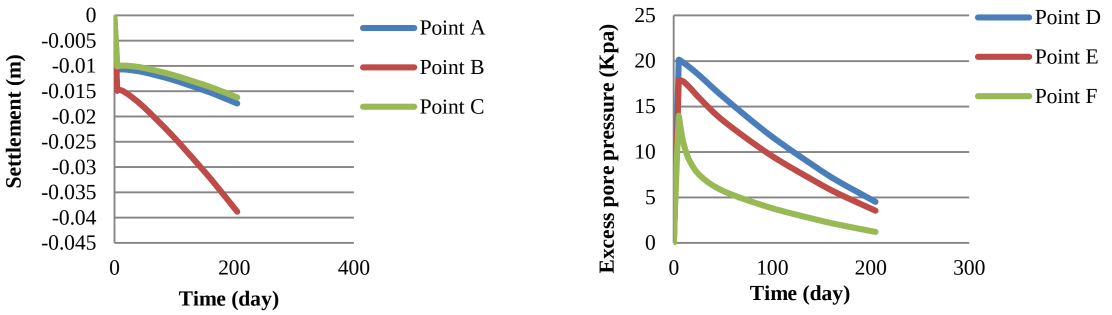
IOP Conf. Series: Materials Science and Engineering **431** (2018) 112011 doi:10.1088/1757-899X/431/11/112011



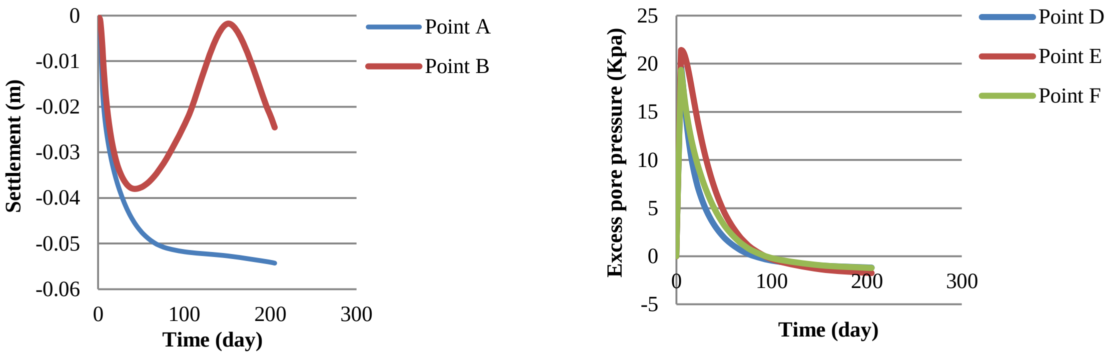
Model 4



Model 5

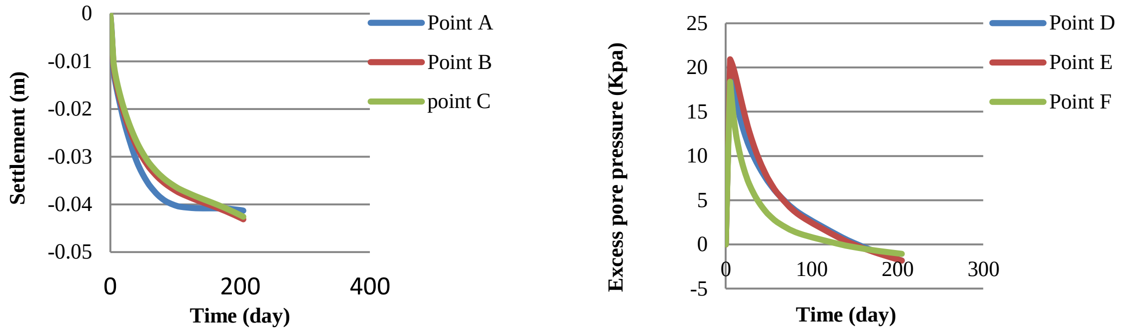


Model 6



IOP Conf. Series: Materials Science and Engineering **431** (2018) 112011 doi:10.1088/1757-899X/431/11/112011

Model 7



Model 8

Figure 6. Models predictions and measurements.

3. Conclusions and discussions

We explored the idea of foundations supported by LCs with different lengths and diameters to support the embankment fill and improve the strength of the soil. The columns are used to improve and strengthen the shallow, soft soil layers. Based on the finite element results, the following conclusions can be drawn:

1. The settlement at the centre is more than that at the toe of the embankment. Furthermore, the maximum settlement occurs at the ground surface and at the centre of the embankment. LCs in proportion of 1:3 is the best choice since it achieves the sufficient settlement and also has the lowest volume of lime, which is expensive, so in overall consideration this design is more sufficient than the others.
2. A faster rate of consolidation considerably increases embankment stability. Longer and more LCs further support the embankment.
3. The FEM analysis revealed that settlement starts instantly during the construction and continues eventually. Furthermore, the excess pore pressure increased with the depth from the ground surface.
4. Analysis of the embankments without columns revealed that mass stabilisation can be very effective in the designs.

Acknowledgments

The authors gratefully acknowledge the financial support from the Fundamental Research Grant Scheme (FRGS) (Project No: FP004-2014B) and University of Malaya Research Grant (No. PG242-2015B).

4. References

[1] Stab ES Development of design and construction methods to stabilize soft organic soils: design guide soft soil stabilization, industrial and materials technologies programme (Brite-EuRam III), European Commission. CT97-0351, Project No. BE. 2002:96-3177.

[2] Kivelö M *Stabilization of embankments on soft soil with lime/cement columns* (Doctoral dissertation, Institutionen för anläggning och miljö).

[3] Goda Y Research Group of Marine Observation Data Analysis and Application 2002 Tide Observation, Coastal Development Institute of Technology, 188p. Korean Translated textbook was published by KORDI in. 2003.

[4] Broms BB 2003 Deep soil stabilization: design and construction of lime and lime/cement columns. Stockholm, Sweden: Royal Institute of Technology

[5] Brinkgreve RB, editor. Plaxis: finite element code for soil and rock analyses: 2D-Version 8:[user's guide]. Balkema; 2002.