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Numerical analysis of embankment resting on floating bottom ash columns improved soft soil

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Abstract. The construction of embankment over soft clay is quite a challenging job for the geotechnical engineer, which may results in a large settlement, bearing failure and stability issues. Stone columns can be used to minimize the settlement and increase the bearing capacity in such conditions. This study was carried out to investigate the behaviour of bottom ash columns underneath embankments using numerical modelling. The soft soil improved with bottom ash columns under the embankment subjected to traffic-induced loading was simulated in Plaxis 3D foundation software. The study variables include three area replacement ratios (Ar) of 10%, 15% and 20% and two columns length of 5m and 7.5m. The results indicated that enlarging the Ar and length of columns significantly reduced the final settlement and consolidation time. The maximum settlement reduction of 58% was reported for the Ar of 20% with 7.5m column depth. The study suggests that bottom ash columns can be used to improve soft soil underneath the embankment.

1. Introduction

The construction of embankment over soft clay is an extremely difficult job for geotechnical engineers because of probable bearing failure, large settlement and instability [1]. However, various improvement methods are adopted to cope with such problems. Granular column method such as stone columns has been captured close attention as a soil stabilization method for speedy construction of embankment on soft clay [2]. The use of stone columns in the soft clay enhances the load-carrying capacity, decrease the settlement due to loading and accelerate the consolidation process [3-7], as well as reduce the liquefaction potential [8]. The construction of stone columns makes a stiffer combined material as compared to the existing soft clay, which achieves the load-carrying capability through the confining effect offered by the adjacent soil [5, 9].

Several studies have been conducted to examine the performance of stone columns applied to improve soft clay under embankment through experimental investigations, numerical modelling, and mathematical techniques. The findings obtained have been proven that the formation of stone columns substantially reduces the settlement and total stress acting on the weak soil bed [1, 4, 10-13]. Stone columns are usually constructed using primary aggregate or natural stone aggregate. The uncontrollable use of these materials has resulted in unavailability and environmental issues. However, the usage of recycled materials is one of the alternatives to obtain protracted period development in ground improvement [14].

Bottom ash is an industrial by-product generated during the electricity production process in coal-fired power stations [15-16]. In developed countries, a certain amount of bottom ash is effectively utilized, but in developing countries, the bottom ash is directly discarded as a landfill due to the low cost of disposal [17]. The disposal of bottom ash in landfills resulted in a threat to environmental conservation. However, previous studies reported that bottom ash posses low compressibility and higher shear strength [18-19] and a higher coefficient of permeability [17]. Bottom ash provides good drainage capacity and more resistance to clogging in comparison to ordinary aggregate columns [20]. Marto, Hasan, Hyodo and Makhtar [21] reported that ground reinforced with bottom ash columns demostrated rapid completion of full consolidation and increased apparent cohesion in comparison to the unreinforced case.The application of bottom ash columns under footing loading demonstrated a decrease in settlement and gain in load-carrying capacity [22-23]. However, a study is needed to investigate the behaviour of bottom ash columns under the embankment.

The objective of this study is to analyze the performance of bottom ash columns under the embankment subject to traffic-induced loading. Plaxis 3D foundation software has been used to simulate the behaviour of unreinforced and bottom ash columns reinforced soft soil under the embankment. The influence of area replacement ratio and column penetration depth on settlement behaviour has been studied.

2. Numerical Modelling

A full-sized embankment built on a 10m thick soft clay reinforced with bottom ash columns was simulated in three dimensional (3D) plane strain. The numerical model of the untreated case was selected as a baseline as shown in figure 1(a). As a result of the symmetry of the model, half of the segment was modelled in the numerical simulation [24]. The soft ground was modelled using the Soft Soil Model (SSM), while Mohr-Coulomb Model (MCM) was used to simulate the embankment and bottom ash columns as elastic-perfectly-plastic material [25-26]. The bottom ash columns with 1.2 m diameter were modelled as a drained material and the interface between columns and soft soil was adopted as fully coupled for simplicity motive. The materials properties adopted in the modelling are tabulated in table 1. The materials properties were obtained from the experiments carried out at Universiti Teknologi Malaysia. A surcharge of 10, 15 and 20 kPa was applied to simulate the traffic loading on the embankment surface. Yan and Yang [24] used a surcharge of 15 kPa to model the traffic loading on embankment surface. In China, the usual traffic loading in the design specification is 20 kPa while 13 kPa is typically adopted in the United States [27]. Therefore, the 20 kPa traffic loading was applied in increments on the surface of the embankment.

The following variables/factors have been analysed numerically.

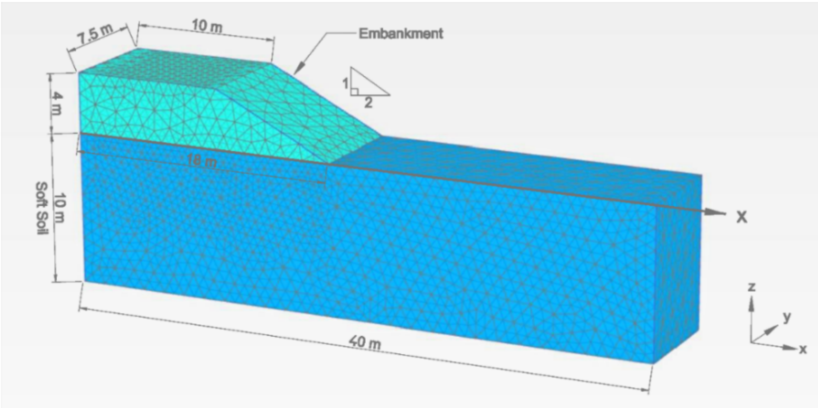
(a) Area replacement ratio: 10%, 15% and 20%. Increasing the area replacement ratio reduces the spacing between columns.

(b) Column length: Two-column lengths of 5m and 7.5m were used in this study. Figure 1(b) show the 7.5m deep bottom ash columns.

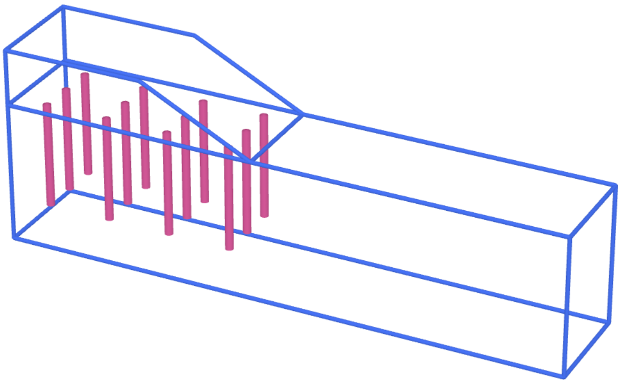
2.1. Settlement versus time relationship

The settlement variation with time for the embankment resting on the weak soil reinforced with bottom ash columns of 5m and 7.5m subjected to the traffic-induced loading of 10, 15 and 20 kPa is shown in figure 2 (a and b). Similar settlement behaviour with time was observed by Wei, Wang and Wu [28]. The settlement is higher for the treated case initially, which demonstrate that consolidation occur rapidly with installation of bottom ash columns. However, the final settlement was higher for the untreated case as compared to the bottom ash columns reinforced models. The final vertical displacement was reduced for a higher value of Ar and columns length. For the reinforced embankment models, the maximum settlement of 47 mm was observed for the Ar of 10% and 5 m deep column, while the minimum settlement was noticed for the Ar of 20% with a 7.5 m deep column. Overall, the application of bottom ash columns resulted to shorten the consolidation time and reduced the final settlement.

The percentage final settlement reduction for the columns improved models in comparison to the untreated case is shown in figure 3. The embankment model resting on columns improved soil with Ar of 20% and 7.5 m column reinforcement depth decreased the settlement by 58%.



(a)



(b)

Figure 1. Plaxis 3D models (a) Embankment on soft soil, (b) bottom ash columns.

Table 1. Summary of parameters used in numerical modelling obtained from experiments.

		Soft Clay	Embankment fill	Stone column
Parameter	Symbol	SSM	MCM	MCM
Sat. unit wt. (kN/m^3)	γ_{sat}	18	18	14
Permeability coefficient (m/day)	k	0.385E-3	-	15.55
Effective cohesion (kN/m^3)	C′	8	20	6
Friction angle (deg)	ϕ	16	0	32
Compression index	Cc	0.65	-	-
Swelling index	Cs	0.065	-	-
Poisson ratio	ν	0.15	0.45	0.3
Elasticity	E	-	10000	14000

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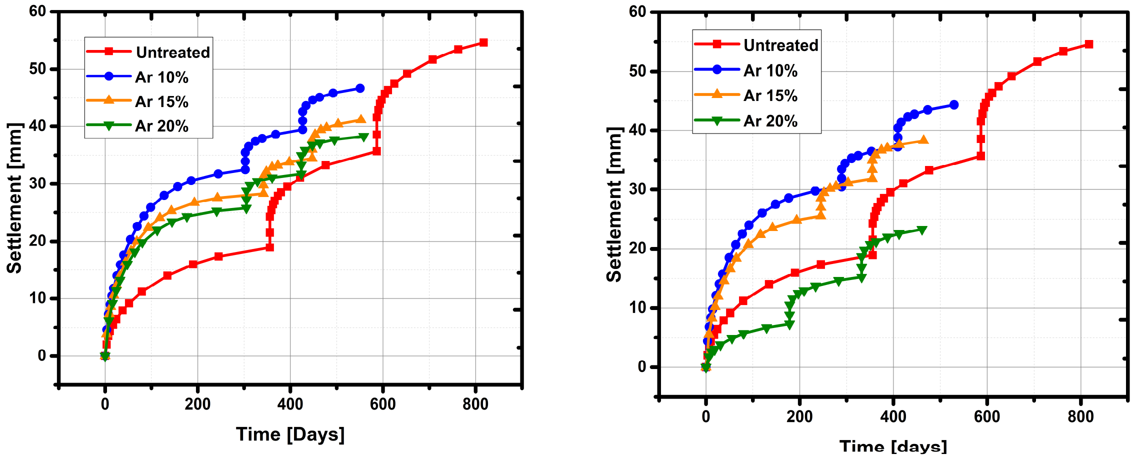


(a) (b)

Figure 2. Settlement versus time relationship (a) columns length 5 m (b) column length 7.5 m.

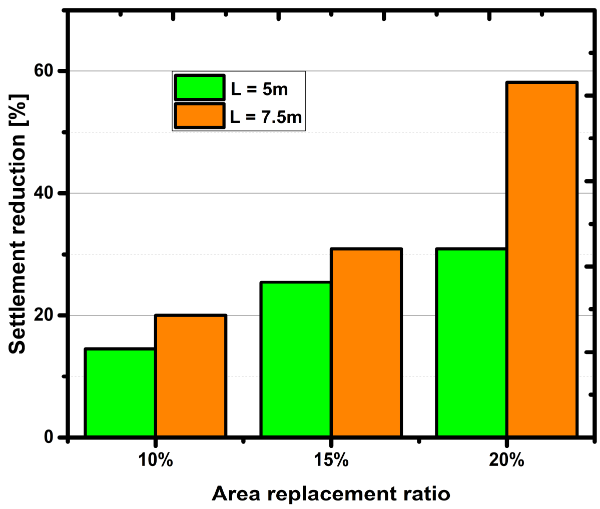


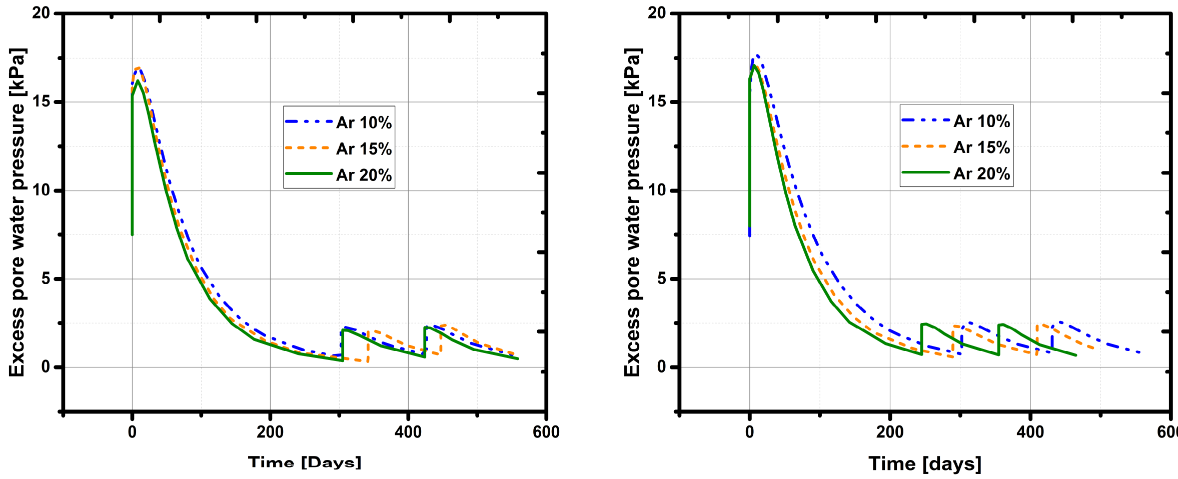
Figure 3. Percentage settlement reduction corresponding to the area replacement ratio.

2.2. Excess pore-water pressure versus time

The excess pore-water pressure distribution with time for the models improved with 5 m and 7.5 m bottom ash columns are presented in figures 4 (a and b). Chen, Li, Xue and Feng [29] obtained a similar response of excess pore-water pressure for the stage loadings acting on the embankment supported on encased stone column reinforced soil. The excess pore water pressure increased initially with load increaments and then approached zero with time under the application of traffic loading 10, 15 and 20 kPa. The excess pore-water pressure was reduced with enlargement in the Ar.

3. Conclusions

In this study, numerical modelling was carried out to analyze the behaviour of embankment supported on bottom ash columns improved soil. The effect of parameters such as area replacement ratio and columns length on the time dependent changes in settlement and pore water pressure due to traffic loads were investigated. It was observed that the final settlement reduced with an increase in area replacement ratio and cloumns length.The maximum settlement reduction of 58% was observed for the model with Ar of 20% and column penetration length of 7.5 m. The results also revealed that excess pore-water dissipated rapidly for the higher area replacement ratio and column length. Based on the outcomes of this study, it is suggested that bottom ash can be used in columns to improve soft soil under the embankment.



(a) (b)

Figure 4. Excess pore-water pressure distribution against time (a) columns length 5 m (b) column length 7.5 m.

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