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Comparison of Coupled Flow-Deformation and Drained Analyses for Road Embankments on CMC Improved Ground

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Abstract

The use of controlled modulus columns (CMC) is gaining increased popularity in the support of rail and road bridge approach embankments on soft soils. The further columns are driven into the competent firm soils, the further the design will rely on the inclusions to take the bulk of the vertical loads, as they become rigid inclusions. The advantage of this design approach is that it produces increased control over the settlement, but as a result the columns will attract greater loads, including bending moment and shear force in situations where non-uniform loading or ground conditions exist. The load on the composite soil-CMC is uniformly distributed by the upper layer of granular load transfer platform (LTP), which also includes a layer of reinforcement. Finite difference program FLAC3D has been used to numerically simulate an embankment on the improved ground with end-bearing CMC. A geosynthetic reinforcement layer has been simulated using the inbuilt $FLAC^{3D}$ geogrid element. In this paper, a comparison has been made between the drained and coupled flow-deformation analyses. The force in the reinforcement layer, in particular, has been compared for the two analysis approaches. It was found that according to the numerical simulation, the drained analysis provides lower estimates of the settlement, lateral displacement; and therefore, predicts less tension in the geosynthetic layer.

Keywords: Ground improvement, Controlled modulus columns, FLAC 3D, Coupled flow-deformation, Drained

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1 Introduction

Bridge approach embankments constructed on soft ground are prone to long term settlements which could potentially lead to unacceptable differential settlements at the interface with the piled foundations of the bridge. Constructing controlled modulus columns (CMC) is one of the most effective methods to minimize such differential settlements when there is a stringent settlement criterion and tight schedule; however, there are less costly methods of ground improvement such as preloading and vertical drains (Azari et al., 2014; Parsa-Pajouh et al., 2015). Unlike piles with a reinforced slab, the load is shared between the soft soil and CMC; however, rigid inclusions may also share the load with the surrounding soil by using shorter length for piles or extending a limited length in the stiff layer (Wong and Muttuvel, 2012). Nevertheless, the load transfer mechanism is very different for the rigid piles where the load is transferred through a rigid reinforced concrete slab. Fioravante (2012) showed through centrifuge physical model tests that the existence of a granular layer beneath a raft changes the pile shaft behavior significantly due to the generation of negative skin friction compared to the case where the pile is in direct contact with the raft. With no pile cap and/or reinforced concrete (RC) slab and using shorter length of inclusions, CMC has proven to be a more cost effective option compared to piled foundations (Yee et al., 2012).

There have been several numerical studies on geosynthetic reinforced column supported (GRCS) embankments. Numerical modeling is a flexible way to improve our understanding of the geotechnical problems due to its cost and time efficiency compared to experimental modeling. Many studies on geosynthetic reinforced embankments have used two dimensional or axisymmetrical models for numerical simulations (Yapage et al., 2015; Jenck et al., 2007; Han and Gabr, 2002).

Ariyarathne et al. (2013) evaluated the different methods to convert a three-dimensional problem into a two-dimensional model, and compared the results from different conversion approaches. They concluded that the equivalent area method yields the closest results to the three-dimensional model. However, even the results from the equivalent area method are different to three-dimensional simulation which is a more realistic approach. Where the embankment side slope effect is not taken into account, unit cell concept is utilized to axisymmetrically approximate the problem. Smith and Filz (2007) investigated this approximation by comparing the results with a three-dimensional model. They concluded that the axisymmetric analyses produce realistic values of average vertical stress acting on geosynthetic reinforcement in column-supported embankments. However, axisymmetric analyses are not expected to produce realistic values of tension in the geosynthetic reinforcement. In the present study, full three-dimensional models have been simulated to model the realistic pattern of the columns, and also take the slope batter effect into account.

Usually, to avoid the complications of the coupled modeling, long term or short term behavior of the model is investigated only by assigning drained or undrained moduli to the material. In this research, coupled hydraulic and mechanical analysis was performed for a long period and was compared with the drained analysis results.

2 Numerical Modeling

Finite difference program FLAC (Fast Lagrangian Analysis of Continua) is widely used to simulate geotechnical problems (Hokmabadi and Fatahi, 2015; Fatahi and Tabatabaiefar, 2014). Finite difference program FLAC3D (version 5.01) was used in this study for numerical modeling. Two types of analyses were performed to compare the results for both approaches. The geometry and the mesh used for the models are presented in Figures 1and 2. Since the embankment is symmetrical in cross-section, half of the embankment has been modeled. The model is considered to be very long in the traffic direction; therefore, one row of columns has been simulated to save the calculation time. The columns are circular in cross-section, and interface elements have been considered between the