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Application of Stone Columns on Slopes Stability Using Numerical Analysis

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Abstract

A two-dimensional (2D) finite difference method was adopted in this study to estimate the factor of safety (FS) against deep-seated failure of embankments over stone column-improved soft clay based on individual column and equivalent area models. In the equivalent area model, the equivalent parameters (unit weight, cohesion, and friction angle) for the improved area were estimated based on the area average of the parameters from stone columns and soft clay. The factors influencing the FS against deep-seated failure of embankments over stone column-improved soft clay were investigated including the spacing, size, and friction angle of stone columns, cohesion of soft clay, friction angle of embankment fill, and existence of ground water. The comparative study shows that the FS values obtained by the equivalent area model are higher than those by the individual column model. The existence of the water table and pore water pressure reduced the frictional shear strength of the improved foundation.

Keywords: Stone columns, embankment stability analysis, finite difference method, safety factor

1. INTRODUCTION

Slope stability analysis of earth slopes are routine calculations in geotechnical engineering. Slope stability is required in construction projects involving excavation, embankments, earth dams etc. Construction of embankments on soft clay is very challenging task for geotechnical engineers due to possible bearing failure, excessive settlement and local and global instability. Use of stone columns below the embankments reduces the excessive settlement, improves the stability and increases the bearing capacity of soft foundation soil with additional advantage of providing a drainage path.

Slope stability analysis can be carried out by the limit equilibrium method (LEM), the limit analysis method (LAM), the finite element method (FEM), and the finite difference method (FDM) (Han and Leshchinsky, 2006; Cheng and Lau, 2008).

In recent years, finite difference method has been widely used for analyzing slope stability including the computation of its factor of safety (FS) (for example, Dawson et al., 1999; Cala and Flisiak, 2001; Han et al., 2002; Cala and Flisiak, 2003a,b; Shukha and Baker, 2003; Han and Leshchinsky, 2004; Han et al., 2004; Richards and Reddy, 2005; Apuani et al., 2005;Han et al., 2005;Won et al.;, 2005; Cheng et al., 2007; Han et al., 2008; Sun et al., 2008; Srivastava and Sivakumar Babu, 2009). Dawson et al. (1999) indicated that the FS values of unreinforced slopes obtained using the finite difference method were in good agreement with those using the other methods with a log-spiral slip surface. Han et al. (2002) used the same finite difference software to obtain the identical corresponding FS values of unreinforced and geosynthetic-reinforced slopes as the Bishop's simplified method.

The finite difference method is perhaps one of the oldest numerical techniques used for solving sets of differential equations. In the finite difference method, every derivative in the set of governing equations is replaced directly by an algebraic expression written in terms of the field variables at discrete points in space; these variables are undefined within elements, finite difference methods have the following advantages for calculating the factor of safety of slope stability (Dawson and Roth, 1999; Cala and Flisiak, 2001): (1) no need to define a range of trial surfaces and possible failure modes or critical slip zones determined from the numerical results (e.g., strain rate, plasticity); (2) no need to assume any functions for inter-slice force; (3) different failure surfaces possibly occurring at the same time; (4) structural elements used to better simulate inclusions (e.g., rock bolt, soil nail or geogrid) instead of equivalent forces; and (5) the solution consisting of kinematically feasible mechanisms.

The slope instability of embankments may develop locally, near the facing, within the embankment, or through the foundation soil as local, surficial, general, or deep-seated failure, as shown in Fig 1. The deep-seated slope failure is also referred to as a global slope failure, mainly induced by a weak foundation existing