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Numerical Analysis of Stone Columns-Supported Embankments

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Abstract

In this study, an evaluation has been performed on a numerical model by the code of PLAXIS based on finite element method to see the effect of stone columns (SCs) placed vertically in a soft soil slope in terms of slope stability and settlements. Effect of s/D ratios (distance between the vertical axes of SCs/diameter of SCs) was investigated on slope stability and settlement of embankment. This study, analyzed numerically in two dimensions under plain strain conditions by Mohr–Coulomb model. The analysis were performed by the PLAXIS code for various slope angles β, ratios of c/(γH), and ratios of s/D. It was observed that settlements were decreased after the improvement with SCs. From the analysis performed, it was found that the SCs increased the stability of slope 1.14- to 1.72-fold as a relative effect of different parameters.

Keywords: Embankment stability analysis, finite element method, stone column, safety factor.

1. Introduction

In last decades, rapid increment of population rate, economic, and social developments has forced to use lands that were unsuitable for construction earlier, so that new engineering solutions must be generated to use these types of lands. Improvement of soils in these lands became an important matter for civil engineers and especially for geotechnical engineers. In the years of 1950 s, soil improvement has become an important application area in geotechnical engineering and many numbers of improvement techniques were developed. A number of ground improvement techniques have been successfully adopted to prevent deep-seated slope failure, such as sand compaction piles, stone columns, and deep mixed columns. Stone columns have been commonly used as an alternative to solve deep seated slope stability problems.

Stone column technique that is one of the soil improvement techniques in which some additive materials are added into the soil can be defined as a good improvement technique to improve bearing capacity, settlement, reduction on liquefaction risk, and slope stability in soft and loose soils that do not have the proper quality for the planned super structure. Stone column technique has been used commonly for 30 years in all over the world (Connor and Gorski 2000; Kumar 2001; Nalc¸akan 2004; Heitz et al. 2005). 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).

Use of SCs in soft soils has emerged as a major ground improvement technique for the last three decades. Stone columns are used to increase the bearing capacity of soft soils (Murugesan and Rajagopal 2006; Ambily and Gandhi 2007), to reduce settlements (Nalc¸akan 2004; Tan and Khine 2005; Patel and Shroff 2005), to decrease the risk of liquefaction (Adalier et al. 2003; Han and Ye 2002), and to increase stabilities of natural slopes and embankments (Kirsch and Sondermann 2003; Han et al., 2008; Sun et al., 2008; Srivastava and Sivakumar Babu, 2009).

Investigations about the slope stability have been focused on the improvement of engineering properties of natural soils lying under man-made slopes, especially under filled areas. Thus, the main objective of these investigations was to improve the stability of these kinds of slopes. 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 under the embankment. Local and surficial failures develop at a shallow depth (mostly less than 1.2 m) due to low overburden stress, low density, low strength, and seepage force when the slope becomes saturated after rain. The general slope failure typically occurs through the toe of the slope (Han et al., 2004).