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Deformation and consolidation around encased stone columns

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ABSTRACT

A new analytical solution is presented to study soft soil improvement by means of encased stone columns to reduce both settlement and consolidation time. The proposed solution aims to be a simple and useful tool for design. Only a unit cell, i.e. an end-bearing column and its surrounding soil, is modelled in axial symmetry under a rigid and uniform load. The soft soil is treated as an elastic material and the column as an elastic–plastic material using the Mohr–Coulomb yield criterion and a non-associated flow rule, with a constant dilatancy angle. An elasto-plastic behaviour is also considered for the encasement by means of a limit tensile strength. The solution is presented in a closed form and is directly usable in a spreadsheet. Parametric studies of the settlement reduction, stress concentration and consolidation time show the efficiency of column encasement, which is mainly ruled by the encasement stiffness compared to that of the soil. Column encasement is equally useful for common area replacement ratios but columns of smaller diameters are better confined. Furthermore, the applied load should be limited to prevent the encasement from reaching its tensile strength limit. A simplified formulation of the solution is developed assuming drained condition. The results are in agreement with numerical analyses.

1. Introduction

Stone columns are one of the most common improvement techniques for foundation of embankments or structures constructed on soft soils. They are vertical columns in the ground, filled upwards with gravel compacted by means of a vibrator. Unlike other improvement techniques, stone columns are considered to not affect significantly the properties of the surrounding ground. The main effects usually considered with respect to the untreated ground conditions are: improvement of bearing capacity, reduction of total and differential settlements, acceleration of consolidation, improvement of the stability of embankments and natural slopes, and reduction of liquefaction potential.

The vertical capacity of stone columns is related to the lateral confinement provided by the surrounding soil. Very soft soils may not provide enough lateral support for a proper performance of a stone column treatment. The undrained shear strength of the surrounding soil is generally used as the criterion to decide the feasibility of the treatment, with lower bound in the range 5–15 kPa (Wehr, 2006). In recent years, geotextile encasement has been successfully used to extend the use of stone columns to extremely soft soils. Apart from the lateral support, geotextile encasement acts as a filter between clay and sand; this ensures the effective drainage and avoids contamination of the sand with fines. Lately, other geosynthetics, such as geogrids, are also used for column encasement (Sharma et al., 2004; Gniel and Bouazza, 2009) because of their high tensile stiffness, yet they cannot avoid sand contamination.

Besides experimental work, most of the research on encased stone columns is done using numerical methods (e.g. Murugesan and Rajagopal, 2006; Malarvizhi and Ilamparuthi, 2007: Yoo, 2010) and very few analytical solutions are available (Raithel and Kempfert, 2000; Pulko et al., 2011). This paper presents a new analytical solution to study the settlement reduction and the acceleration of consolidation caused by encased stone columns. The proposed solution is an extension of another analytical solution recently developed by the authors for stone columns (Castro and Sagaseta, 2009). The solution assumes linear elastic behaviour of soil and linear elastic-perfectly plastic behaviour of encasement and column. Furthermore, the proper loading history is considered (undrained loading and consolidation analysis), and equilibrium and compatibility conditions, both in vertical and radial directions, are fulfilled. So, many of the limitations of the existing analytical solutions (Raithel and Kempfert, 2000) are overcome.

The analytical solution gives a quantitative assessment of the improvement introduced by the column encasement and the influence of its stiffness on the system performance. The axial

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