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Influence of geotextile encasement on the behaviour of stone columns: Laboratory study

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ABSTRACT

This paper presents a study of the influence of the geotextile encasement on the behaviour of soft soils improved with fully penetrating encased columns. This influence is analysed by means of measuring soil-column stress distribution, pore pressures and soil deformation during the consolidation process. For this purpose, a horizontal slice of a representative “unit cell” has been analysed by means of small-scale laboratory tests. The tests were carried out in a large instrumented Rowe-Barden oedometric cell. Results showed that the vertical stress supported by encased columns is about 1.7 times that sustained by the non-encased ones. The stress concentration factor for encased columns is between 11 and 25, which is clearly higher than that obtained in tests with non-encased columns, which are between 3 and 6. Finally, the improvement in relation to settlements is presented by the ratio of settlement in soils reinforced with ordinary or encased columns and the settlement of non-treated soft soil. This settlement reduction factor is around 0.6 when the soil is treated with encased columns and 0.8 for soil with non-encased columns.

1. Introduction

Encased stone columns are widely employed in very soft soils ($s_u < 15$ kPa) to improve bearing capacity, to reduce settlements and to increase the speed of consolidation. Columns act as relatively rigid and permeable inclusions in the soft soil allowing for the reduction of settlements, the increase of bearing capacity, and the reduction of time needed for consolidation. The effectiveness of its performance is mainly based on the soil-column load distribution, which largely depends on the lateral support provided by the soft soil. In very soft soils, with undrained shear strengths lower than some limit between 15 and 5 kPa (Wehr, 2006), this lateral support is not sufficient, and columns may fail because of excessive bulging (McKenna et al., 1975). In these situations, one widely employed solution to enhance the performance of this treatment is to wrap the columns with a geosynthetic encasement. The main advantages of encased columns compared to ordinary columns are the extra lateral support provided by the geotextile encasement, and stopping fine particles of the soft soil squeezing inside the column avoiding clogging. This technique has been successfully employed in foundations of roads and railways under embankments (Raithel et al., 2005).

The use of encased stone columns among the last decades has come with an increase in studies performed to analyse their behaviour. One of the first attempts was presented by Van Impe (1989). Since then, several analytical studies have been developed such as Castro and Sagaseta (2011, 2013), Pulko et al. (2011) and Raithel and Kempfert (2000).

In addition to analytical research, several numerical studies have been performed. Some of them presented parametric studies focused on the influence of the stiffness of the geotextile encasement (e.g., Almeida et al., 2013; Malarvizhi and Ilamparuthi, 2007; Murugesan and Rajagopal, 2006) or on the influence of the encasement length (e.g., Dash and Bora, 2013). Most of the numerical studies have been performed using 2D simulation but there are also some 3D approaches (e.g., Keykhosropur et al., 2012; Lo et al., 2010; Yoo, 2015; Yoo and Kim, 2009).

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Numerous experimental studies related to encased columns have also been developed. Full-scale tests were performed in several analyses (e.g., Alexiew et al., 2009; Almeida et al., 2015; Chen et al., 2015; Hosseinpour et al., 2015; Raithel et al., 2002; Yoo and Lee, 2012), although small-scale laboratory tests were carried out in most of the studies. In these last cases the column diameter is significantly smaller than that in real treatments and the geotextile sleeves are generally formed by a flat fabric with a longitudinal joint; however, continuous sleeves are usually employed in real treatments. This joint in laboratory tests is commonly made by an overlap of the fabric, which can be sewn (e.g., Hong, et al., 2016; Murugesan and Rajagopal, 2007, 2010) or it can be glued (e.g., Ghazavi and Afshar, 2013; Gniel and Bouazza, 2009, 2010). This results in a weak point that reduces the strength of the geotextile (Alexiew et al., 2012). The majority of these experimental studies focus on the load-settlement response (e.g., Gniel and Bouazza, 2009; Murugesan and Rajagopal, 2007, 2010).

The objective of this research is to analyse the influence of the encasement on stone columns by means of small-scale laboratory tests. The main novelty of this research is the analysis of settlements, total stresses and pore water pressures not only for drained conditions but also during the whole consolidation process. This is accomplished by performing experimental laboratory tests in a large diameter oedometric cell. The research is focused on soil-column stress distribution, settlements and pore pressure dissipation in soft soils treated with encased columns. In addition, the improvement achieved when the stone column is encased with a geotextile is compared with non-encased columns.

2. Experimental set-up

In real treatments under large uniformed loaded areas, stone columns are installed forming meshes of regular patterns (triangular, hexagonal or square). A widely employed simplification for their analysis is the consideration of one single column and its corresponding surrounding soil which is referred to as “unit cell”. The laboratory tests were designed to study fully penetrating encased columns, neglecting tip effects, with no influence of the column length and only radial drainage. This allows simplifying the analysis to a slice of a “unit cell” at a certain depth. For this purpose, small-scale laboratory tests were performed in a Rowe-Barden oedometric cell (Rowe and Barden, 1966), 254 mm in diameter and 146 mm height. The geometry of the unit cell was defined by a diameter ratio of $N = 3$ (N, ratio between diameter of the elementary cell and column diameter). This corresponds to a column diameter of 84.7 mm and to an area replacement ratio of $a_r = 11\%$, resulting a scale of the tests about 1/10 respect to real cases. Regarding the boundary conditions, only radial drainage towards the column was allowed and equal strain condition was simulated by placing a rigid plate on the top surface.

The oedometric cell was instrumented focussing on the study of column-soil stress distribution, pore pressure dissipation and measurement of the rate of strains during the consolidation process. With this aim 6 pore pressure transducers (PPT) and 7 total stress transducers (TST) were allocated in the base of the oedemetric cell. Total stresses under the column were measured by three TST (XPM10-50G-HA-LC1, QBM, pressure cells 8 mm in diameter) placed in a triangular pattern, at 22.5 mm from the centre of the cell. Total stresses on the soil were measured by 4 TST (XPM10-10G-LC1, QBM, pressure cells 8 mm in diameter) which were placed at different distances from the centre ($r = 49$, 58, 69 and 115 mm). Pore pressures (WF17060, Wykeham Farrance, pressure cells 4 mm in diameter) were also measured at different distances from the centre ($r = 49$, 53, 58, 69, 84.5 and 115 mm). Fig. 1 shows the instrumented base. Two horizontal TST (XPM10-10G-LC1, QBM, pressure cells 8 mm in diameter) were placed diametrically opposed in the lateral boundary of the cell at 20 mm height from the base to measure horizontal stresses on the soil. Finally a LVDT was set up at the central point on the top of the cell to measure vertical displacements. More details of the instrumentation can be found in Cimentada (2009) and Miranda (2014).

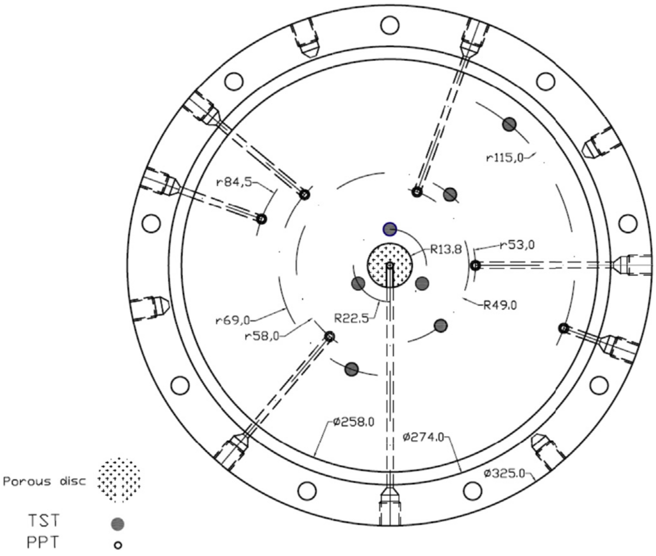

Fig. 1. Instrumented base of the Rowe-Barden cell.

2.1. Characterization of the materials

Kaolin clay was employed as soft soil, limestone gravel for the column and two different geotextiles as encasements.

Relevant properties of the kaolin, obtained from laboratory tests, are summarised in Table 1 (Cimentada et al., 2011).

Uniform gravel with particle sizes between 4 and 5 mm was used for the column, according to the 1/10 scale of the test. The maximum and minimum dry unit weights are 16.5 and 13 kN/m^3, which correspond to void ratios of $e_{min} = 0.64$ and $e_{max} = 1.06$ respectively. A relative density of 50% was chosen to form the column which corresponds to a dry unit weight of 14.5 kN/m^3. Conventional drained triaxial tests were performed to obtain the values of the internal friction angle (ϕ) and the dilatancy angle (ψ). A summary of the most relevant properties of the gravel obtained from these tests is given in Table 2. Laterally confined stress path-controlled drained triaxial tests were also carried out to obtain the oedometric modulus of the gravel resulting in a value of $E_{mc} = 20{,}000$ kPa.

Table 1
Properties of the kaolin clay (Cimentada et al., 2011).

Liquid limit [%]	73
Plastic limit [%]	38
Plasticity index	35
c_v [cm^2/s]	$2.5 \cdot 10^{-3}$[a]
C_c	0.53
C_s	0.10
e (50 kPa)	1.529
s_u/σ'_v (C–U triaxial tests)	0.30
ϕ [°] (C–U triaxial tests)	26.5

[a] Range from 1.9 to $2.7 \cdot 10^{-3}$ cm^2/s.