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Bridge Pile Response to Lateral Soil Movement Induced by Installation of Controlled Modulus Columns

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Abstract
Controlled modulus columns (CMC) for ground improvement are installed using a hollow stem displacement auger to induce lateral soil displacement effect, followed by grout injection. While the method reduces spoils, the excessive lateral soil displacement may damage adjacent structures. Although there has been growing interest in quantifying such effects, only a handful of studies have been attempted. This paper presents the results of a numerical investigation on the CMC installation effect on an existing bridge pile using the three-dimensional finite difference software package *FLAC^{3D}*. It has been found that when the CMC is long and the existing bridge pile is slender, the pile bending moment and pile lateral movement, induced by the CMC installation effect, can be significant.

Keywords: ground improvement, controlled modulus columns, installation effect, cavity expansion, bridge pile

1 Introduction

The controlled modulus column (CMC) ground improvement technique aims to create an improved composite ground, consisting of a grid of rigid inclusions installed in soft soil overlaid with a granular load transfer layer (Plomteux et al. 2004). The column installation process involves penetrating an auger into the ground under a torque and thrust provided by a drilling rig, followed by grout injection through the hollow stem while raising the tool. The auger is purposely designed to enable lateral soil compaction during augering and prevent the soils from moving upward when raising the auger. When construction sites involving CMC are located in close proximity of existing sensitive structures such as an existing bridge foundation, if proper installation sequence is not considered, the risk of damaging adjacent structures due to lateral soil movement can be high (Plomteux et al. 2004, Brown 2005, and Hewitt et al. 2009). Hence, it is often necessary to prepare a risk assessment and construction planning before construction starts. Although these tasks have become a routine for piling contractors, assessing installation effects, especially the lateral soil

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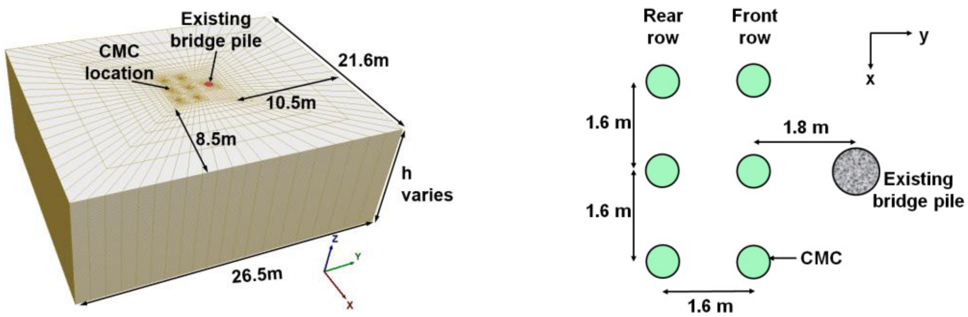
movement due to installation, remains a serious challenge. Available assessment methods for installation effects include the cavity expansion theory (Carter et al. 1979), strain path method (Baligh 1985) and more rigorous analyses using numerical modelling. The cavity expansion theory, which is the most common method, studies the changes in pore water pressure and stresses due to the creation or the expansion of a cavity. Current contributions to CMC application found in the literature include a numerical study by Rivera et al. (2014) based on the cavity expansion theory using PLAXIS-2D and a field investigation of installation effects on the surrounding soils by Suleiman et al. (2015). However, assessment of the CMC installation effects on the adjacent existing structures has not been reported in the literature notably due to a number of reasons. Firstly, the modelling of pile installation process involves large mesh distortion and can be time consuming. Secondly, the existing analytical methods are unable to capture the complex three-dimensional soil-structure interaction and construction sequence. This paper presents a 3D numerical model to investigate the response of an existing bridge pile subjected to loading due to the lateral soil movement induced by the installation of nearby CMCs.

2 Numerical Modelling

To simulate the CMC installation process, three dimensional numerical modelling using $FLAC^{3D}$ v.5.01 was carried out in large strain mode. 3D grids were created to represent a soil profile consisting of a soft clay layer, overlying bedrock (Figure 1a). An existing bridge pile and six proposed CMC positions are located in the centre of the 3D model. The radial cylindrical mesh represents CMCs and piles, while the cubical meshes form the outer soil regions. The lateral boundaries were extended 20 times the CMC diameter, from the outmost CMC or pile to minimize the boundary effects.



(a) (b)

Figure 1: (a) $FLAC^{3D}$ finite difference grid and (b) the layout of CMCs and the existing bridge pile

The existing bridge pile is 0.75 m in diameter (d) and is located at 1.8 m centre to centre (c/c) from the nearest CMC. The pile is assumed socketed into the bedrock. The construction of two rows of CMCs next to the existing bridge pile was simulated in this study (Figure 1b). Each row has three columns oriented in the x-direction. CMCs have a diameter d_{CMC} = 225 mm and spaced at 1.6 m c/c in a square pattern. All CMCs are installed to the top of bedrock or very stiff ground. The model grid is generated using *FISH* programming language to facilitate the parametric studies. The 3D grid shown in Figure 1a developed for a model height h = 9.6 m comprises 179,200 zones and 165,616 grid points.

2.1 Material Model

Soil properties were derived from site investigation data from a highway upgrade project in Australia. The modified Cam-Clay (MCC) material model was adopted to represent the behaviour of the soft clay. The adopted parameters include the slope of normal consolidation line (NCL) λ = 0.29,