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Full Length Article

Numerical modelling of pullout of helical soil nail

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A R T I C L E I N F O

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A B S T R A C T

An investigation into the pullout response of helical soil nail using finite element subroutine Plaxis 2D is presented. The numerical modelling of actual pullout response is achieved by axisymmetric and horizontal loading condition. The effect of varying number of helical plates, helical plate spacing and helical plate diameter is studied to understand the pullout capacity behaviour. The failure surfaces for various helical soil nail configurations and their pullout mechanisms are also analysed and discussed. The pullout capacity is found to increase with increase in number of helical plates. The helical plate spacing ratio (s/D_h) and diameter ratio (D_h/D_s) are found to increase the pullout only up to a critical value. The response of helical soil nail using axisymmetric finite element simulation is found similar to the uplift behaviour of helical piles and helical soil anchors. In the absence of literature regarding numerical modelling of helical soil nail, simulation results are validated with uplift responses of helical piles and soil anchors. A good agreement in their comparative study for pullout response is also observed.

1. Introduction

Simulation of interaction between soil nail and soil is an important issue in modelling a soil-nailed system. This soil-structure interaction is studied in terms of pullout resistance or bond strength of the nails (Liu, 2003; Akiş, 2009). Zhou et al. (2011) developed a three-dimensional (3D) finite element (FE) model to simulate the pullout behaviour of a soil nail in compacted and saturated completely decomposed granite (CDG) soil nail pullout box under different overburdens and grouting pressures by using modified Drucker–Prager Cap model. The stress release variations surrounding the soil nail during drilling, grouting, saturation, and pullout were simulated by the FE modelling and compared with available test data. In their study, Zhou et al. (2011) concluded that the established finite element method (FEM) can well simulate the pullout behaviour and performance of a soil nail in field soil slope. A similar study on the pullout and failure mechanism of soil anchors was also carried out by Zhao and You (2014). Rawat and Gupta (2016a,b) studied the failure mechanism and performance of soil nail in model slope using two-dimensional (2D) FEM.

In order to achieve a sound soil nail-soil interaction, researchers have analysed the use of more rough surfaced soil nails or soil anchors (Frydman and Shaham, 1989; Lutenegger, 2009). More detailed studies in regard to this context have been carried out on the pullout capacity of either screw piles (Kurian and Shah, 2009) or helical screw piles (Rao et al., 1991). In the study conducted by Rao et al. (1991), the impact of number of helical plates on ultimate capacity in clay using model helical screw piles of 75 mm diameter in a bed of compacted clay was investigated. Rao et al. (1991) investigated the failure mechanism variation based on the spacing of the helix and the pile diameter ratio. Two different types of failures, intact cylinders of soil between helical plates for $s/D < 1.5$ and isolated plugs of soil around each helix for $s/D > 1.5$, were observed, where s is the helical plate spacing, and D is the diameter of helical plate. These observations led to the conclusion that the maximum capacity was attained when s/D was between 1 and 1.5. Lutenegger (2009) presented field test data on the uplift capacity of helical piles in clay in comparison to estimated capacities using cylindrical failure and individual plate bearing mechanisms. The study implied that the failure mechanism assumed in design (cylindrical failure or individual plate bearing) ought to depend on s/D.

Several numerical studies have been carried out on the failure mechanism of helical piles, for example, Merifield (2011) used small strain axisymmetric FE simulations of the ultimate uplift capacity of cast-in-place, deeply embedded, horizontal, circular plates at varying s/D to show that the mechanism changed from

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cylindrical shear to individual plate bearing failure at $s/D = 1.58$. It was also observed from this study that axisymmetric analyses did not consider the impact of the pile shaft and the installation process on the ultimate capacity of helical piles. Stanier et al. (2013) studied the effect of active length and helical plate ratio on a transparent synthetic soil using particle image velocimetry. They observed that the pile capacity is dependent on the active length and failure occurs in the form of a cylindrical surface failure. Using the partial factor method in FE analysis, it showed that the active length is governed by the number, spacing and size of individual helical plate. A total of 19 full-scale model tests were carried out to study the compression and uplift capacities of helical piles with installation effort (torque). The FE routine, Plaxis foundation, was used to validate the experimental work. The helical screw nails were simulated using 3 circular pitched bearing plates located at the depth three times the helical plate diameter. FE analysis was also used by Papadopoulou et al. (2014) to study the performance of helical piles under axial and horizontal loadings. The axial and tensile capacities were simulated under axisymmetric condition as a shell foundation. The studies were further extended to investigations on the effect of shear strength parameters and number of helical plates on the characteristic ultimate resistance of piles.

Plaxis 3D was also used for numerical verification of experimental results by Mittal and Mukherjee (2015). They conducted studies on multiple helix piles at different depths of embedment. The investigators also developed correlations between the ultimate compression capacities of multiple helix piles with single helix pile by mathematical formulations. Todeshkejoei et al. (2014) presented a 3D numerical analysis of the installation process for helical anchors in clay. Along with the application of torque-capacity correlation, the results from their analyses can be used to predict the relationship between installation torque and normal force as functions of helix pitch, roughness, and thickness.

In the present study, axisymmetric FE modelling is conducted for simulating pullout mechanism of helical soil nail by Plaxis 2D. From the literature review, it is clear that insufficient information is available with regard to helical soil nail modelling. The literature provides ample data for simulation of helical piles or helical soil anchors. It is also evident from Tan et al. (2008) that the pullout behaviours of soil nails can be well simulated by vertical pullout in axisymmetric condition available in Plaxis 2D package. The horizontal orientation is simulated by applying a horizontal load on the absorbent boundary to account for overburden acting when soil is pulled out horizontally. The literature review further suggests that researchers (e.g. Salhi et al., 2013; Knappett et al., 2014; Demir and Ok, 2015) have modelled helical piles and helical anchors using a similar concept in Plaxis subroutine. Studies based on such modelling techniques have been used to understand the pullout or uplift capacity of helical piles and anchors. Applying the accuracy of this existing modelling technique to actual behaviour, the variation in helical soil nail failure mechanism and pullout capacity with the number, spacing, and diameter of helical plates can be studied. From the literature review, it can also be concluded that the effect of overburden on pullout behaviours of helical soil nails is significant. However, experimental evidence by Tokhi et al. (2016) is the only available data in that context. The FE analysis of such experimental work can further enhance the understanding of pullout responses of helical soil nails.

2. Parametric analysis using finite element

2.1. Helical soil nail

In the present FE analysis, the helical soil nail used is made up of steel with bar geometry taken as per the available dimensions given in ASTM A615 (ASTM, 2002) for threaded nail bars (Lazarte et al., 2003). The diameter of the nail shaft (D_s) is 19 mm with a nominal unit weight of 2.24 kg/m. The helical plates are also considered to be made of steel with diameters varying from 26.6 mm to 83.6 mm. This variation of helical plate diameter is used in D_h/D_s ratios for numerical modelling. All soil nail lengths are fixed to 15 cm as done in the experimental work by Rawat and Gupta (2016a), which is converted for simulation using scale of 1:50 (i.e. 1 cm in experiments equal to 0.5 m in modelling). Thus, the nail length of 7.5 m is utilised in FE analysis. The spacing of the helical plates used is varied with s/D_h ratios to study its effect on helical nail pullout capacity. With the bottom helical plate fixed at 15 mm from the nail end, different depths of embedment of top helical plate is achieved by varying the spacing of the helical plates, which is used in the analysis for embedment ratio H/D_h. A typical helical soil nail modelled in FE analysis is shown in Fig. 1.

2.2. Isotropic hardening soil model

The soil parameters used in FE analysis are taken from the experimental work by Rawat and Gupta (2016a) on reinforced soil slopes. A well graded, isotropic sand size soil is used for constitutive modelling in Plaxis 2D. The soil is modelled as a hardening soil which yields in plastic straining due to soil expansion. The hardening of soil is subjected to shear and compression hardening. The input E_{50}^{ref} is used to model the shear hardening due to the primary deviatoric loading which induces irreversible plastic strains. Irreversible plastic strains are also induced by compression obtained

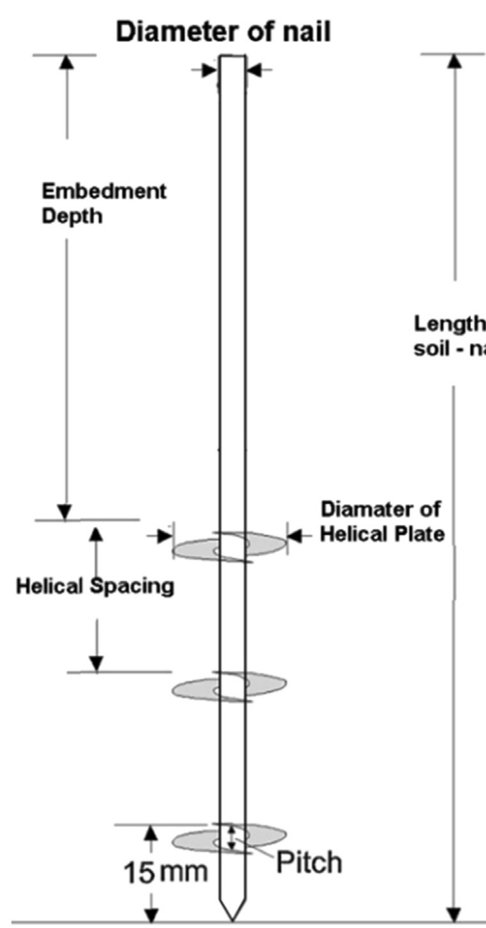

Fig. 1. Soil nail with helical plates modelled in FE analysis.