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Research Paper

Laboratory study of a new screw nail and its interaction in sand

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ABSTRACT

Experimental results of a series of laboratory pullout tests on a new screw soil nail are presented. A review of the literature for the screw soil nails as well as a comparison of its performance with other conventional types of soil nails is discussed. The present investigation also examines the fundamental interface mechanism and attempts to define the associated rupture zones in cohesionless material with the aid of thin vertical bands of coloured sand cast in a large distinctly fabricated pullout box. The philosophy behind the design and development of the new screw nail is briefly described first followed by presentation of the laboratory testing procedure and its instrumentation. The results of the testings indicate that the slip mechanism, which controls the pullout behaviour, is rather different to the conventional soil nails and the resultant pullout capacity is higher when compared to this type soil nails. This effect is attributed to the geometry of the screw nail and the installation processes that result in the development of different soil stresses around the soil nail. In addition, the experimental pullout results demonstrate, contrary to the conventional soil nail, that the screw nail pullout capacity is dependent on the overburden pressure and that the failure planes extends out a certain radial distance from the soil–nail interface. From the test results, it is shown that the failure of the screw nail satisfies the Mohr–Coulomb failure condition, which is similar behaviour seen in the conventional soil nail tests.

1. Introduction

Soil nailing is an *in situ* reinforcement technique that in the usual definition of the term is an annulus soil inclusion in the form of a grouted reinforcement bar and the name ‘nail’ is used as a reference to its functional similarity to fastening nail. The term is now extended for a wider range of soil reinforcement inclusions made and shaped from various materials to strengthen the shear resistance of soil. The concept of the soil nailing as a construction technique in civil engineering seems likely to have evolved from the rock bolting system used in the New Austrian Tunnelling Method [11]. Since its inception in the 1960, soil nailing has been increasingly used to stabilise slopes and excavations similar to an anchor system. The difference being, off course, that soil nailing is a passive system and that unlike anchoring, it is not prestressed. The construction of soil nail typically involve drilling of an inclined bore into the soil, insertion of reinforcing bar, infilling of the bore with grout, affixing nail head to a bearing plate and shotcreting the soil face. Another method for driving long reinforcement bars in soil includes firing using compressed air gun.

This deemed quick turnaround in the construction and the relatively low cost of soil nailing has led to an ever increasing usage of soil nails. In Hong Kong and other rapidly developing cities are being built around fill slopes and earth retaining structures in which the material is known as completely decomposed granite and described as silty sand with some gravels. Junaideen et al. [9] reported a case in point that many of fill slopes have failed due to rainfall causing a reduction in shear strength of soil. In these kinds of fill slopes, and perhaps many other sites with different ground geology, the remedial works are either very time consuming or not possible due to limited access and obstructions such as trees and underground services.

One potential solution for the fore-mentioned fill sites is through the use of conventional grout soil nails for stabilisation work. However, as reported in the literature that the conventional soil nailing technique has a number serious drawback that has not yet been properly understood. Hong et al. [6], for instance, carried out both field and laboratory tests to investigate the effects on grouting and overburden pressures on the conventional grout nails. It was found that the pullout resistance increased linearly with the grouting pressure, but the overburden pressure did not influence the pullout capacity. However, Yin and Zhou [20] carried out similar laboratory study on similar material and found that both grouting and overburden stress have influence on the pullout resistance.

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Su et al. [18] observed from experimental study that the construction processes of soil nail induced significant stress relieve in the soil and that the pullout shear resistance was not dependent on the overburden pressure. Junaideen [8] reported that even though the conventional soil nailing is extensively utilised in Hong Kong for reinforcing of slopes and earth retaining walls, but there is a lack of understanding of the interaction of soil nail in loose fill. It is therefore clear from the experimental and field test results reported in the literature that there is no unanimity of results in the factors influencing the pullout behaviour of conventional soil nail.

Pullout resistance is most important parameter in the design of soil nails and there are many factors that are known to influence this. Some of the factors that are believed to contribute to the pullout resistance are construction method, overburden stress, grout pressure, nail surface roughness and soil strength. The key to understanding the problem of soil nailing is the development of soil nail interface resistance. Several researchers (Cartier and Gigan [2], Milligan and Tei [13], Junaideen [8], Pradhan [15], Su et al. [18], Wu and Zhang [19] and Hong et al. [6]) have investigated this phenomenon by using soil nails.

In order to overcome some of the shortfalls of the conventional soil nailing and to improve the constructability and performance of soil nailing technique, a helical screw nail (shown in Fig. 1) was designed and fabricated to study the influence of the various parameters. The screw soil nail typically consists of shaft with helical flights spaced evenly along the entire shaft. Its resistance is developed through the transmission of the axial stresses to the helical plates. An extensive search of the literature has revealed that the first use of helical soil nail was by Bobbitt [1]. It comprised a tube shaft with single helices spaced at regular intervals and is typically used in foundation anchor. Later, a similar nail was instrumented and installed at a site in 2005 by Missouri Department of Transport (MnDOT), and was reported by Deardorff et al. [3].

The objective of the present research was predominantly to perform pullout tests a new multi-plate helical soil nail in loose fill conditions to investigate the fundamental mechanism and compare its performance with the conventional grout soil nail. In order to conduct the tests, a large scale box together with a loading frame and a pulling actuator were setup.

1.1. Previous works

Various theoretical and empirical methods have been proposed (e.g. [17,2,7,5,13,14]) for the evaluation of pullout resistance of soil nail that is considered an important design parameter, which is often estimated and then verified by proof pullout test during construction. This type of test is particularly useful for studying the fundamental interaction mechanism and the interface shear strength between the soil nail and the soil.

The peak pullout resistance is given by:

$$\tau_{max} = \frac{P}{\pi DL} \tag{1}$$

where P = peak pullout force, D = soil nail diameter and L = length of soil nail.

The coefficients of friction f and μ are given by the following equations:

$$f = \frac{\tau_{max}}{\sigma_n} \tag{2}$$

where

$$\sigma_n = \frac{(1+k_0)}{2}\sigma_v, \quad k_0 = 1 - \sin\phi_{ps}, \tag{3}$$

$$\sigma_v = vertical\ stress, \quad \phi_{ps} = plane\ strain\ friction\ angle$$

and

$$\mu = \frac{f}{tan(\phi_{ds})} \tag{4}$$

For practical use, the pullout resistance in loose granular material can be estimated from the following equation:

$$\tau_s = a + \sigma_n \tan(\delta) \tag{5}$$

where a = apparent adhesion, δ = apparent friction angle and σ_n is as given in Eqs. (3).

More recently helical soil nail has been used to further improve the simplicity and quick construction characteristics of conventional soil nailing. The helical soil nailing offers many advantages over the conventional soil nailing as it does not require any boring and grouting, and therefore, it offers a more economical solution than the conventional method.

Design of helical soil nails differs from the conventional or grouted soil nails. It is understood that for the grouted nail the bond strength is developed at interfaces and for the helical it is assumed to develop at the helices. As yet, there have been no studies undertaken to understand the fundamentals of the mechanism involved in the analysis of helical soil nail. To this end, an experimental study of the fundamental behaviour of a new helical soil nail so called screw nail have been conducted using a large shear box. A brief description of the screw soil nail and the apparatus as well as results of the tests conducted to date are described below.

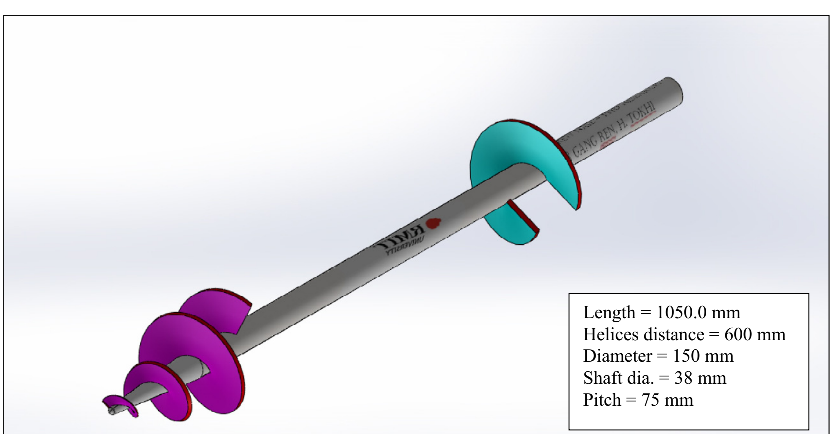

Fig. 1. Fabricated laboratory test model of screw nail.