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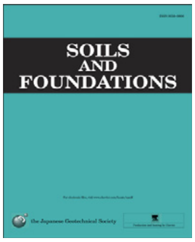

An innovative Geonail system for soft ground stabilization

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Abstract

Soil nails are widely used in stabilizing and retaining the ground during constructions, with the high yield steel bar the most commonly used soil nail material at present. The classical method of soil nail construction is, however, not effective in soft clay as it is difficult to establish a good bond strength and global soil improvement. An innovative soil nail installation method has been developed for the Airport link in Australia, which combines the applications of fracture grouting techniques and composite GFRP soil nails to stabilize the ground soil as well as to compensate for the settlement of ground. Extensive laboratory and in-situ tests have been carried out to verify the mass soil properties methods and the performance of the Geonail system for the local and global stabilization of the soft ground.

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Keywords: Geonail; Soft ground; Stabilization; Fracture grouting

1. Introduction

The concept of soil nailing is to increase the global shear strength of the soil by closely spaced nails. A soil nail is a passive in-situ reinforcement, which responds to movement by mobilizing the nail force. It has been used extensively to retain excavations and stabilize slopes in various countries. The soil nails are usually installed across or behind the potential failure surface to stabilize the global mass. The stabilization forces are provided between the cement grout surface of the soil nails and the soil. In general, the nailing system has the advantages of lower cost, quicker construction procedure and less impact on adjacent ground when compared to other traditional stabilization methods like retaining walls. Currently, the high yield steel bar is the most commonly used material because it is relatively cheap and is simple to install in most cases.

In general, soil nails are not adopted in soft clay because of various uncertainties in their performance in this soil condition. Firstly, the low cohesion of the soft clay equates to small bond strength between the ground and the soil nail, which results in a low pull-out resistance of the soil nails. Meanwhile, it is usually not cost effective to improve the pull-out resistance by increasing the length of the soil nails due to the limitations at the construction site. Secondly, the strength of the soft clay and the friction between the ground and soil nails are small so that it is difficult to stabilize a global soil mass. The function of the soil nail would thus be highly localized unless the soil nails are densely installed, which would be expensive and time-consuming (and a longer construction time means more ground settlement). Thirdly, the displacement can be great because of the creep of the soft clay, which can lead to the

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instability of the soil nail system. Soil nails must be installed as soon as possible after exposure of the ground surface in the soft ground. In addition, the underground water can cause seepage and piping during the excavation of the soil, which can influence the strength of soil nail greatly if global stabilization is not carried out as soon as possible. Since there are so many problems to overcome, soil nails are generally not recommended in soft clay, though there have been some reports for their successful use.

Fracture grouting has been successfully adopted in different projects for settlement compensation for more than 30 years. Based on the recent research on displacement grouting by Soga et al. (2001) and Au et al. (2007), subsurface cavity expansion in clay induced by fracture grouting is not only able to generate upward displacement of clay, but there is also an increase in the effective stress leading to consolidation which results in settlement compensation and shear strength enhancement in normally consolidated clay. As a result, fracture grouting can be a cost effective technique for ground improvement in soft ground condition.

Fracture grouting combined with the use of composite Glass Fibre Reinforced Polymer (GFRP) soil nails for maintaining the tunneling face stability was first adopted in the Airport Link tunnel project in Brisbane Australia. The Airport Link is a tunneled motorway grade road in the northern suburbs of Brisbane, Australia. It connects the Brisbane central business district and the Clem Jones Tunnel to the East–West Arterial Road which leads to the Brisbane Airport. It was built in conjunction with the Windsor to Kedron section of the Northern Bus way in approximately the same corridor. The Airport Link and bus way project involved 15 km of tunneling including the road (5.7 km of twin tunnels), bus way tunnels and the connecting ramps as well as 25 bridges and result in over 7 km of new road. The tunnel section under the QR railway embankment at Toombul was installed by the box jacking technique. The construction of the launch box requires 85,000 m^3 of soil to be excavated under the railway embankment, and had posed a major challenge to the construction with the poor soil condition. The ground is mostly soft clay, which is very prone to subsidence. As a requirement of this project, the railway had to be maintained in operation during the whole construction to ensure the transportation. It was extremely important to control the settlement of the embankment, which greatly increased the difficulty of the construction. The alluvial soil comprises of layers of soft, firm to stiff sandy clay, and the geological profile and the property of the ground soil are shown in Table 1 and Fig. 1. The SPT value of the soft clay is less than 10 while the friction ratio from CPT test ranges between 2% and 4% with a mean pore pressure of about 0.12 MPa. For the firm clay, the SPT value of the soft clay is about 20 while the friction ratio from CPT test ranges between 4% and 8% with a mean pore pressure of about 0.38 MPa. The soil properties for the soft clay in Table 1 have clearly illustrated the difficulty in maintaining stability and reducing settlement during construction.

Table 1
Averaged properties of ground soil (Young's modulus determined from dilatometer, vane shear and CPT tests) (value in bracket represent the range of the values).

Soil	Shear strength (kPa)	Young's modulus (MPa)	Water content (%)	Plasticity index
Soft clay	20 (15–27)	6 (4–8.5)	57 (52–59)	25 (23–27)
Firm clay	37 (30–47)	20 (17–29)	46 (44–49)	45 (41–49)

In order to minimize the settlement, headwalls, canopy tubes, soil nails and sidewall steel tubes were constructed to retain the railway embankment for the excavation of box jacking shafts. The stabilization measures and the finite element mesh used for the modeling of the jacking process are shown in Fig. 2.

Ground improvement works underneath the QR railway embankment were required to facilitate the box jacking stages. Large volumes of grout were injected into the ground to stabilize it prior to excavation. In order to optimize the ground improvement, Geonails were introduced into the project. The geonails used in this project, which are shown in Fig. 3, are essentially a combination of soil nails and Tube a Manchette (TAM) grouting. For the main face nails, it was formed from GFRP rods placed around the circumference of the TAM sleeve. The GFRP rods were developed and tested for this use so that they could be easily broken out as part of the excavation by mechanical plant. By adopting Geonails, the physical properties and pull-out strength of the soil nails in soft clay were improved by consolidation through the introduction of grout finger networks. The soil nails provided positive reinforcement for the excavation face slope and improved the soil strengths due to consolidation effects and grout replacement. The combination of soil improvement and soil reinforcement had maintained the stability of the face and limited the settlements of the railway and enabled the installation of the jacked box beneath the embankment.

During box jacking, the mixed soft/stiff clay excavation face was maintained at approximately 60° to the horizontal (similar to the jacked box leading edge angle) by GFRP fracture grouted soil nails. No soil nail was proposed in the Siltstone strata with an in-situ strength greater than 1 MPa due to its coherent stability and strength. The soil nails were installed on a dense grid (i.e., at close spacing) through the gaps between the headwall piles during excavation of the jacking pit and extend across the entire length of the box jack. Sufficient anchoring force at the western end of the soil nails were developed by keying into a grouted groundmass on the western side of the railway. The GFRP soil nails provided sufficient tensile strength

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