An Innovative Post Grouting Technique for Soil Nails

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Abstract This study presents an innovative technique of executing soil nails called sectorized post grouting (SPG). The most utilized technique of soil nail grouting is gravity grouting, with the literature reporting advances in pressurized grouting. Although obtaining higher pullout resistance of soil nails, pressurized grouting, mostly done in single-stage grouting, does not compensate for exudation and its use in higher nail lengths is difficult. Thus, a technique has been developed that compensates for exudation, with easier application in lengthier nails. The technique was qualitatively assessed to evaluate its surface roughness and later applied in seven real soil nailing works, where it could be quantitatively assessed. The results show that sectorized post-grouted nails obtained greater pullout resistances than gravity grouted and single-stage grouted nails. Although similar improvement was found in tube-à-manchette (TAM) grouted nails, this method presents lower economic efficiency than sectorized post grouting. The pullout resistance results obtained in this study can be utilized in future soil nailing works executed utilizing SPG.

Keywords Soil nailing · Grouting · Pullout Test · Bond Resistance · Sectorized Post Grouting

1 Introduction

Soil nailing is a ground reinforcement technique that can be used for retaining existing cuts and top-down construction of basements. For proper behavior of soil nailing retaining walls, a target value \( q_s \) of the interface resistance of inclusions inserted into the soil, called nails, has to be achieved. Nails are critical to the behavior of soil nail walls, as they increase the shear strength of soil by skin friction between the soil mass and the grout.

During the execution of soil nails, especially in the drilling stage, there may be features that are difficult to reach the target value of the interface strength. Thus, to compensate for the deconfinement of the borehole by drilling and to improve the surrounding soil by cavity expansion, pressurized grouting has been replacing the conventional technique of gravity grouting the cavities.

The literature’s most reported pressurized grouting techniques achieved better results than the conventional gravity grouting method, utilizing single-stage grouting, such as reported by Hong et al. (2013), Seo et al. (2012), Wang et al. (2017), Ye et al. (2018) and Yin et al. (2009). Nevertheless, in single-stage grouting, the effects of grout exudation are likely to occur in any type of soil mass, resulting in voids between the nail and the ground, reducing the lateral area of the nail and, consequently, the strength of its interface is not compensated.
A technique called sectorized post grouting (SPG), which not only compensates for the deconfinement of the cavity but also reduces the deleterious influence of exudation, is described. SPG conception and effectiveness were assessed initially by exhumating the nails in an experimental site in tropical soil. The noticeable higher surface roughness of the interface, the expected higher dilatancy of the post-grouted nails, and the avoidance of rework due to unattained pullout resistance motivated the use of this technique in real soil nailing works.

This paper reports the development of the technique and its verification by pullout tests in seven soil nailing walls in Brazil. In these walls, all nails were executed by SPG.

2 Conventional Soil Nailing Grouting

The conventional execution of the soil nailing technique begins with drilling; thus, there is a local deconfinement of the soil mass, with progressive plastic yielding and induced displacements towards the hole’s interior, resulting in a material with worse geotechnical properties around the hole after the redistribution of stresses has taken place within the soil body. Subsequently, the grout is gravity injected from the bottom of the hole to the whole surface. The process is shown in Fig. 1.

In conventional soil nailing, where there is no grouting pressure, the surroundings of the soil mass do not return to the pre-drilling stress state and the adhesion of the grout to the interface, despite offering pullout resistance, is lower compared to the properties of the soil mass if it were intact, e.g., without deconfinement and with the same geotechnical properties prior to drilling.

Thus, a technique that would at least restore the original stress field conditions around the soil mass before drilling was proposed. This alternative was conceived as a more feasible option than the solution of increasing the number of soil nails in a soil nailing retaining wall, which is a solution still used to compensate for the lower pullout resistance available. In order to achieve the goal of using the smallest number of soil nails and avoiding rework, a system that allows the possibility of pressurized grouting was proposed.

Su et al. (2008) reported findings that soil nail pullout resistance is hardly dependent on the overburden stress in conventional soil nailing, a hypothesis confirmed by Yin & Zhou (2009), which also found a dependence of the pullout resistance on the grouting pressure. Yin et al. (2009), Hossain & Yin (2011), Seo et al. (2012), Hong et al. (2013), Wang et al. (2017), and Ye et al. (2018) also observed an increase in the pullout resistance due to pressure grouting for pressurized single-injection cases. However, the method of soil nailing execution conceived in the papers mentioned above does not compensate for the effects of grout exudation, which is deleterious due to reduced dilation at pullout (Moosavi et al., 2005).

Besides not compensating for exudation, some soils do not allow the effective introduction of single packers, which is a method employed in the studies of Seo et al. (2012) and Hong et al. (2013), nor the use of hole plugging near the face of the slope, method used by Yin et al. (2009) and Hossain and Yin (2011). In addition, obtaining high enough pressures in one stage is troublesome in higher nail lengths, such as in compaction grouted soil nails (Ye et al. 2018). Thus, it was conceived a methodology that could be used regardless of the type of soil mass inspired by the execution of tube-à-manchette (TAM) grouting.

3 Sectorized Post Grouting Development

Camberfort (1968), by studying the TAM technique, observed the possibility of post grouting by "claquage", changing the soil mass so as not only to recondition the hole surroundings to the initial stress field but also to increase the minor principal stress (σ₃) to a state higher than existing levels, altering the behavior of the soils from normally consolidated to overconsolidated and from loose to dense, increasing dilatancy. Therefore, the dilatancy angle of the
soil was expected to increase (Roscoe 1970). TAM grouting is also associated with soil shear strength gains and is a very effective post-grouting technique in ground anchors (Kim et al. 2012).

Recently, an innovative nail was presented by Cheng et al. (2013), who studied TAM grouting associated with Glass Fibre Reinforced Polymer (GFRP) nails and reported the improvement not only in the dilatancy angle, as reported by Seo et al. (2012), but also of the shear strength of the soft clay being injected due to consolidation, as reported by Kim et al. (2012).

Although TAM grouting can effectively improve the shear strength of soil and pullout resistance of nails, it still is a time-consuming and labor-intensive method, reducing the feasibility of use in soil nailing walls, which usually present a high density of nails per square meter of the retaining wall.

Therefore, a methodology analogous to TAM grouting was developed, but one that would result in more expeditious one-step execution, representing less rework and labor use, with less sophisticated equipment, with similar improvement on the pullout resistance of the surrounding soil properties. Figure 2 shows the schematic and actual details of the nails before insertion into the hole, and Fig. 3 illustrates the steps of SPG.

Figure 4 illustrates trial nails in normally consolidated soft clays executed for qualitatively evaluating the technique in terms of surface roughness since rougher surfaces result in higher interface resistance.

As seen in Fig. 2, the technique consists of the association of flexible plastic hoses (usually polyethylene) inserted into the hole along with the nails. The hoses have sealed ends, being fragile at certain points along their length in places where grout, usually at a water/cement (w/c) ratio of 0.7, is to be reinjected. The hoses comprise the whole length of the hole to evenly reinject the nails and avoid any points that may have impaired pullout resistance due to deleterious effects of binder exudation and deconfinement of the hole.

These fragile points, commonly referred to as valves, are those where holes or tears in the hose are made, protected only by a gummed tape, or the like.

**Fig. 2** Detail of hoses installed for reinjection, adjacent to reinforcement bar and centralizers

**Fig. 3** Sectorized post grouting methodology. In addition to the grouting of the sheath, as in gravity grouting, there are added steps of sectorized reinjection of the nail from the bottom of the hole to the face of the slope, performed after 12–24 h of gravity grouting (modified from Souza et al. 2015)
to insulate the inside of the hose during the insertion of the nails and avoid grouting entering the hose.

After 12 to 24 h of gravity grouting the hole, the SPG is performed. This is done by employing a slender, simple packer inserted into the upper end of each hose. The control of grouting pressure is done by slowly increasing the pump pressure, until there is a sudden drop, indicating a local fissure at the gummed tape valves where grout can interact with the surrounding soil, as observed in exhumation, with the fissure filled with grout (Fig. 4). As the reinjection is performed in the upper end of the hoses, the use of a double packer is avoided, saving labor and material costs.

Although Fig. 2 shows a nail installed with three hoses, the number of hoses depends on the length of the nails. In the trial nail works, as seen in Fig. 4, it was found that each hose sector, in terms of surface roughness, could satisfactorily reinject the soil, i.e., with much higher surface roughness than a perfectly cylindric nail, up to 3.0 m. Sector lengths greater than 3.0 m resulted in lower surface roughness. For instance, considering these observations, a nail with 9.0 m would have at least three hoses installed along the reinforcement bar, each with 3.0 m spacing between valves, resulting in three sectors, as seen in Fig. 3.

For similar volumes of injected grout, where the total grout volume is comprised of grout volume injected through gravity grouting added to the volume injected through SPG, the mean diameter was approximately the same, but with a much rougher surface when SPG was used. The promising results in surface roughness and the higher confinement due to high grout injection pressures motivated the execution of more sectorized post-grouted trial nails for pullout tests for quantitative validation of the technique.

3.1 Field Pullout Tests in Soft Clay

For these field pullout tests, six steel bars of 240 kN yield and 22.25 mm diameter were used, with a total length of 4.0 m. The free length was 1.0 m, necessary because when applying the tension load to the bar, the face and the ground are subjected to compression loads, risking obtaining inaccurate results. The holes were drilled with a hand-held drill, and the injection, made upwardly from the bottom of the hole, was previously stirred in a high turbulence mixer with a w/c ratio of 0.5, expected to achieve at least 0.8 MPa in 24 h. The free length was surrounded by graphite grease and a protective tube to avoid friction between bar and grout in the free length. The scheme of the pullout tests can be seen in Figs. 5 and 6.

The surrounding soils around all soil nails were a residual, non-structured soft clay, with an NSPT of 2. Three of the nails were manufactured utilizing gravity grouting. The remaining three nails were executed utilizing SPG, with one sector of polyethylene hose with fragile points every 0.5 m into the grouted length of 2.0 m.

Two LVDTs were installed on the support structure to measure displacements. It adopted a criterion that considered that if there was 1 mm of
displacement but less than 1% increase in the measured load, the nail had reached the maximum safe load. The stabilization criteria were respected at each loading stage, starting at the alignment load of 5 kN and increased in 10 kN per time interval, with readings being taken at the following time intervals: 0 min; 1 min; 2 min; 4 min; 8 min; 15 min; 30 min, and 60 min. Table 1 summarizes the results of the tests, where N is the number of blows of the SPT test and $q_u$ is the ultimate interface resistance. Figure 7 shows the load–displacement curves of the pullout tests results of gravity grouted nails, and Fig. 8 of the pullout tests results of sectorized post grouted nails.

It was observed that the load–displacement curves of sectorized post-grouted nails were noticeably more linear than the load–displacement curves of gravity-grouted nails.

By observing Table 1 and Figs. 7 and 8, SPG could be seen as an effective technique, at least in soft clay, with a mean improvement of 176% in the soil nails pullout resistance compared to the conventional technique.

Motivated by these results, SPG was adopted in different soils in real soil nailing works in Brazil. During these works, it was attempted to verify by field pullout tests the assumption that the improvement in soil nails pullout resistance in soft clay would be repeated in other types of soils.
4 Field Pullout Tests of Sectorized Post Grouted Nails in Real Soil Nailing Sites

From the successful experiments of SPG in soft clay and the evidence that pressure grouting obtains improved pullout resistance in soils where suction is not excessive (Hossain and Yin 2011), seven soil nailing retaining walls were built utilizing the SPG technique in seven different soils in Brazil.

Each with more than 1500 nails, these works were executed using the SPG methodology. These nails were tested as seen in the soft clay experiments, with 1.0 m of free length and 3.0 m of anchored length for the sacrificially tested nails.

The tests were performed on 1.0% of the nails of each site, resulting in at least 15 nail pullout tests per site performed with the SPG methodology. A view of one of these sites can be seen in Fig. 9.

The field pullout tests were made at the beginning of each site on nails whose elevation was at a maximum depth of 5.0 m from the excavation base. The results were computed relating the pullout resistance to the number of blows N of the SPT test, the most utilized site investigation test in Brazil. N is the tripod-mounted manual blow counts of the last 30 cm penetration of the conventional Raymond-Terzaghi sampler, no liner, used in the SPT. Table 2 shows, for each site, the soil type, the N, the mean \( q_s(\mu_{qs}) \), the standard deviation of \( q_s(\sigma_{qs}) \) and the w/c ratio of the grout.

Although not optimal, the relationship between N and \( q_s \) was intended to be compared with the one Ortigão and Palmeira (1997) proposed, an estimation widely utilized in Brazil to estimate the pullout resistance when designing soil nailing walls. Figure 10 summarizes the results of the field pullout tests obtained in the sites, showing the relationship obtained, seen in Eq. 1, while also showing the relationship obtained by Ortigão and Palmeira (1997) for high-quality control works performed with gravity grouting, seen in Eq. 2.

\[
q_s = 118 + 8.2N \quad (1)
\]

\[
q_s = 67 + 60.1N \quad (2)
\]

It is emphasized that Site 1 and Site 3 were made in problematic soils. Site 3 was an unconsolidated fill where the expected pullout resistance by Eq. 2 was 192 kPa, 48% superior to the results obtained in the field. Ortigão and Palmeira (1997) also collected data from a porous clay, characteristic of Site 1, and their results presented a field pullout resistance 63% superior to those obtained in Site 1. Taking off Site 1 and Site 3 from the data in Fig. 10, the new relationship obtained can be seen in Fig. 11 and presented in Eq. 3.
The main results of this study show that sectorized post-grouted nails achieve greater pullout resistance than the results obtained in gravity grouting nails. According to the measurements, normally consolidated clays, unconsolidated clays, sands, silt, and saprolites, presented higher shear strength at the interface of the nails and, consequently, a higher $q_s$. Notably, for the sandy silt of São Paulo, there was an increase of more than 400% in pullout resistance compared to conventional gravity grouting. For the porous clay, where the smallest increase in the pullout resistance of the nails was found, it was still obtained an increase of 58% compared to the results illustrated by Ortigão and Palmeira (1997).

Despite the significant dispersion, it was clear that SPG achieved greater pullout resistance than those found by Ortigão and Palmeira (1997) conventional empirical rule for gravity grouted nails. Also, compared with the results of Cheng et al. (2013), it was found that SPG led to an improvement of similar magnitude to the improvement achieved by TAM grouting, despite the lesser time, labor, and material costs involved in the former technique.

The results in predominant silt deposits were the most surprising, due to the considerable increase of $q_s$, even for smaller $N$ values. This behavior is assumed to be due to the greater confinement provided around the nail, the larger lateral area due to the larger volume injected into the nails, and the smaller spacing between nails used in the executed works, up to 1.5 m. The combined factors possibly compensated for the lower cohesion of such predominantly silt soils.

5 Conclusions

In this study, after observing the main deleterious influences on pullout resistance of gravity grouted nails and the possible increase in dilation due to pressurized grouting, an alternative technique of nail execution, called sectorized post grouting, was conceived. The technique aimed to perform pressurized injections at weak points of hoses installed along the length of the nails, namely in each valve, after grouting of the sheath. The main findings of this study are listed below:

(a) It was found that the new technique obtained higher pullout resistance of the soil nails when compared to soil nails executed by gravity grouting and single-stage pressurized grouting.
(b) The new technique compensates for grout exudation, and, by sectorizing pressurized grouting, it is effective in lengthier nails.

$q_s = 190.24 + 5.38N$  

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This trend was found for all soil types tested, confirming studies by Yin et al. (2009), Hossain & Yin (2011), Seo et al. (2012), Hong et al. (2013), and Wang et al. (2017) for pressurized grouting. It is noticeable SPG obtained greater improvement in pullout resistance than single-phase pressurized grouting.
(c) The technique, although presenting greater economic efficiency than tube-à-manchette (TAM) grouting, obtained similar improvement effects in pullout resistance compared with nails executed by TAM grouting. Nevertheless, it still is more time consuming and requires greater control of the operative daily procedures than works executed by the gravity grouting technique.

(d) The sectored post grouted nails pullout resistance results obtained in this study can be utilized to design future soil nailing works, which opt for utilizing the technique of SPG. It appears to be economical and has proven safe and advantageous in several studied sites in Brazil mentioned herein. Further research, however, is going on to fundament further the new technique to other conditions and environments.

Acknowledgements The authors would like to acknowledge the Graduate Program of the University of Brasilia, which helped fund this project, and the various contractors and designers who allowed the use of the data in this article, especially George Joaquim Teles de Souza from Solotrat Geotechnical Engineering.

Author Contributions “All authors contributed to the study conception and design. All authors read and approved the final manuscript.”

Funding This work was supported by University of Brasilia.

Data Availability The datasets generated or analyzed during the current study are not publicly available due to not being published elsewhere but are available from the corresponding author on reasonable request.

Declarations

Competing Interests “The authors have no relevant financial or non-financial interests to disclose.”

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