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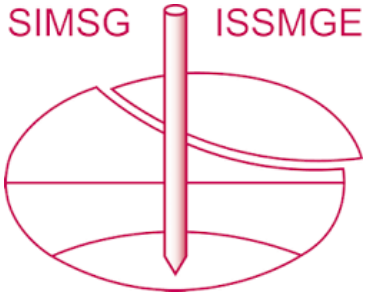

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Behaviour of nails reinforcing an open excavation in gneissic residual soil

Comportement des clous pour renforçant une excavation ouverte en sol résiduel de gneisse

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ABSTRACT

This paper reports on the stress-strain-strength behaviour of nails in a 40m high excavation in gneissic residual soil, near to city of Rio de Janeiro, Brazil. Instrumentation included inclinometer and tell-tales for monitoring horizontal displacements of the soil mass. Strain gages were also placed on the steel bars for obtaining tension and bending along the nails. The results from the monitoring program allowed identifying the stress and strain distributions along the nails during the excavation progress and for more than one year after the field work was completed. Moreover, the measured nail's strains and stresses allowed the speed of the excavation work to be closely controlled. Distinct construction stages of strength mobilization were identified. Design concepts and construction details are discussed, together with details of the calibration and monitoring program.

RÉSUMÉ

Cet article présente le comportement contrainte-déformation-résistance des clous dans une excavation de 40m de hauteur dans le sol résiduel gneissique, près de à la ville du Rio de Janeiro, Brésil. L'instrumentation a inclus l'inclinomètre et les transduteurs mécaniques pour surveiller des déplacements horizontaux du massif de sol. Des jauges extensométriques ont été également placées sur les barres en acier pour obtenir les déformations et contraintes le long des clous. Les résultats de la surveillance ont laissé identifier les distributions de déformations et des contraintes le long des clous pendant l'excavation et pour plus d' un an après que les travaux sur le terrain ont été accomplis. D'ailleurs, les mesures de déformations et de contraintes des clous ont permis le contrôle de la vitesse d'excavation. Des étapes distinctes de la mobilisation de force pendant la construction ont été identifiées. Des concepts et des détails de construction sont discutés, ainsi que des détails du programme de calibrage et de surveillance.

Keywords: Soil nailing; instrumentation, monitoring, strain gauges, tell tales, inclinometers.

1 INTRODUCTION

Nailing has proved to be an efficient technique for stabilizing soil or rock masses, in special in situations with restrictions in space, cost or deadline. It is applicable for reinforcement of potentially unstable natural slopes or vertical excavations.

The installation procedure usually consists of positioning the steel bars into a pre-drilled hole and then grouting in place. The holes are nearly horizontal, in a slight downward inclination. The external slope surface has no structural function, but may be protected with a metallic grid and then shotcreted. Details on design and construction procedures of soil nailing structures were reported by Clouterre (1991), Schlosser et al. (1992), GEO (1996) and Ortigao & Sayao (2004).

Effective mobilization of the nail resistance restricts the displacements of the soil or rock mass. For this reason, the performance and safety of a soil nailing excavation shall be monitored by proper instrumentation of the reinforced slope. Soil displacements and nail tensional loads are recommended to be monitored during all construction phases.

In most countries, nailed slopes are not usually instrumented, limiting information on inherent deformations or soil-nail interaction during the progress of the excavation. This paper aims at reporting on a comprehensive monitoring program and results of a high nailed excavation in a residual soil slope.

2 DESCRIPTION OF THE NAILED EXCAVATION

The monitored excavation was situated in Niteroi, a coastal city about 15km distant from Rio de Janeiro, Brazil. The soil nailing excavation, about 40m high and 50m long, was carried out for creating space for waterfront residential buildings of ten floors. Figure 1 shows a frontal view of the excavation. The upper part was protected with grass and the lower part was reinforced with nails. Design details were reported by Sayão et al. (2005).

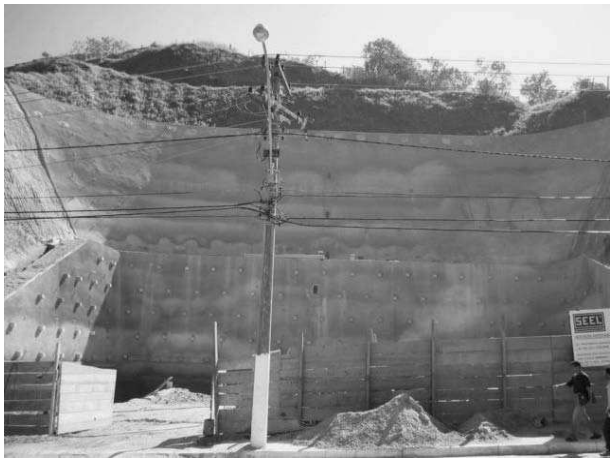

Figure 1. Frontal view of the 40m high nailed excavation.

Local geology is typically composed by gneissic residual soils, which could be classified in two types – a mature residual soil, predominantly red sandy clay in the upper 10m, and a young residual soil, in the inferior part, characterized by a

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clayey sand with a lighter color. Details of local geology have been presented by Gomes Silva (2006) and Nunes et al. (2008).

3 INSTRUMENTATION AND MONITORING

The instrumentation program focused on monitoring the geotechnical behavior of the excavation during and after construction. Horizontal displacements at several points were measured by inclinometers and tell-tales positioned along the central vertical sections of the nailed slope. Tensional loads developed at the strain gauged nails were also determined at successive excavation phases. The two cross-sections of instrumented nails (sections A and B) were 4m apart. Strain gauges were glued onto the steel bars. Six lines of tell-tales with 4 units in each were installed between instrumented nails. Two inclinometers were also available in each vertical section, as shown in Figure 2.

Monitoring was carried out from March 2004 to August 2006. Results were reported in detail by Lima (2007), and instrumentation procedures were shown by Nunes et al. (2006).

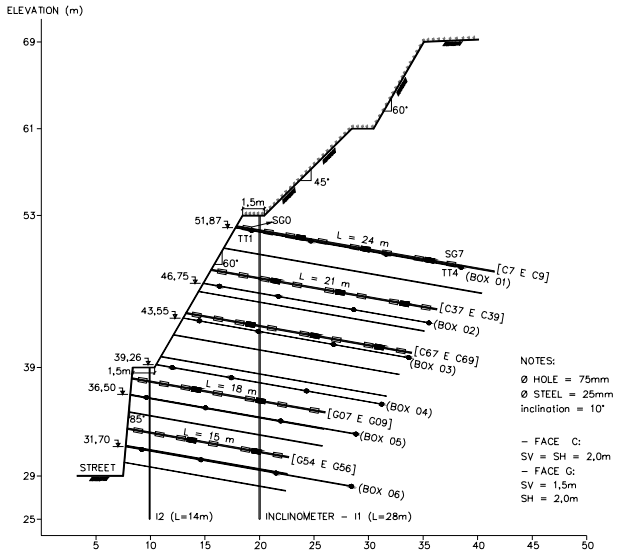

Figure 2. Typical instrumented cross-section of the nailed excavation.

3.1 *Inclinometers*

Two inclinometer tubes were installed in vertical holes of 50mm diameter. These inclinometers were successful in indicating the zones of large shear strains within the nailed mass and for revealing the rate of displacements during the excavation.

Two boreholes of 100mm inner diameter were done by rotary drilling for installing the inclinometer tubes. These holes were positioned at elevation +53 e +39, about 1.0m from the excavation face. The two holes reached the depths of 30.0m and 16.7m, respectively. The water level was not found during the drilling operation.

3.2 *Tell-tales*

Several units were installed for monitoring the displacements in specific points within the nailed mass. These devices, together with the inclinometers, provided data for analyzing the behavior of the excavation. Zones of large shear strains and potential failure surfaces within the reinforced slope may be detected by these devices.

The tell-tales were positioned in pre-bored holes of 100mm diameter, at selected elevations, made by compressed air drilling at 10^o inclination to the horizontal. In each hole, four tell-tales were introduced in 10 or 12mm plastic tubes for protection of the steel cables, whose typical lengths were 1.5m, 7.0m, 14.0m, and 28.0m. The cables were anchored to steel bars (12.5mm in diameter) at the borehole's inner end. After positioning the tell-tales, the holes were filled with cement grout, with a water–cement factor (W/C) of about 0.5 in weight.

At the slope face, the horizontal cables were connected to 500gf metallic dead weights through pulleys, for keeping the cables stretched. Displacement readings were indicated on a fixed millimeter scale by a needle attached to the cable. The scale was glued inside a metallic closed box, which was fixed to the slope face and provided protection to the four tell-tales (Figure 3). Details of installation and monitoring procedures were reported by Nunes et al. (2006).

Figure 3. Metallic box with four tell tales.

3.3 *Strain gauged bars*

Nails are made of steel bars surrounded by cement grout. The bars may be instrumented with electrical extensometers (strain gauges), the main advantage being the lower cost when compared to vibrating wires or LVDTs. Strain gauged nails are capable of providing accurate readings of about 10-6 mm/mm. However, strain gauges require special care for gluing, connecting and protecting against temperature changes or mechanical damage.

Most manufacturers offer strain gauges of 120 or 350 ohms resistance for steel bars. The 120 ohms strain gages are less expensive and exhibit lower sensitivity than the 350 ones. Both types must be excited by a steady power source. In this research, 120 ohms strain gauges, with gauge factor of 2.0, were chosen.

Strain gauges were glued on the steel bars, aiming at monitoring the axial load distribution along the nails, during the field excavation work. Nails C07 e G07 had strain gauges also glued in a diametrically opposed position, aiming at monitoring and quantifying bending moments on the steel bar. Extensometer spacing was about 2m to 3m, concentrating at the regions of high tensional load (Figure 5).

Procedures for preparing the instrumented nails have been described by Springer (2006) and Lima (2007). Calibration and acquisition details were described by Proto Silva (2005) e Sare (2007). A comprehensive program of field pullout tests on instrumented nails was carried out at the same site. Results of interface strength q_s were reported to have an average value of 200kPa (Springer, 2006).

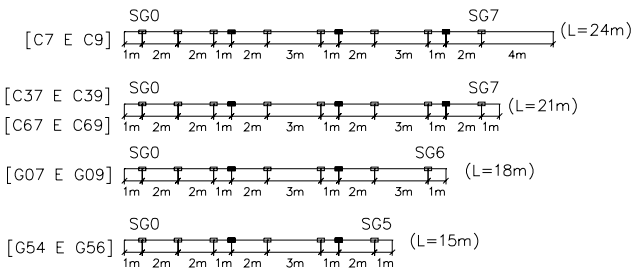

Figure 5. Relative position of strain gauges on the steel bars.

Strain monitoring in the strain gauged nails was done by using a full Wheatstone bridge circuit for each strain gauge. Strain gauges were connected to the bridge by three wires, for minimizing the effects of temperature changes and differences in wire length (Nunes et al., 2006).

The output of each bridge circuit was decoded and stored in millivolts in a data acquisition system. This system was excited by a 3V external electrical power source.

Special attention was required for gluing and wiring the strain gauges. Improper contact or external factors like traffic vibrations, moisture or strong winds may cause sudden changes in the acquisition readings.

The acquisition software was set for storing data in 6s intervals with 1 microvolt resolution and 5% accuracy. The stored data was statistically processed, eliminating inappropriate data outside the pre-fixed limits of one standard deviation from the average value. These frequent readings were important for confirming the stability of the acquisition system.

The strain (ε) at a given position along the nails was computed by Equation 1 (Perry and Lissner, 1962):

$$\varepsilon = \frac{4.\Delta L}{(V_{exc} + 2.\Delta L) \cdot Gf} \quad (1)$$

where V_{exc} is the bridge's excitation voltage, Gf is the gauge factor and ΔL is the voltage difference at the bridge's terminals.

Tensional loads were computed by Equation 2, which was experimentally obtained by calibration tests (Saré, 2007):

$$F\ (kN) = 4.316 \times \varepsilon \times 10^3 \quad (2)$$

The magnitude of the bending moments (M) was determined from the strain readings in each pair of strain gauges glued on the steel bars at diametrically opposite positions (Perry and Lissner, 1962; Adams, 1975), considering the expression:

$$M = \frac{\pi \cdot \phi_{st}^3}{64} \cdot E_{st} \cdot (\varepsilon_1 - \varepsilon_2) \quad (3)$$

where ε_1 and ε_2 are the strain values given by the strain gauges; ϕ_{st} is the steel bar diameter and E_{st} is the elastic modulus of steel.

4 INSTRUMENTATION RESULTS

Figure 6 shows the horizontal displacements profiles from inclinometer I2. The nailed excavation took place from May 26 to August 12, 2004. The progressive increase in displacements may be noted to occur during and also after the excavation.

Similar results were registered from tell tales, also indicating the increase in horizontal displacements during and after the excavation progress. The importance of maintaining the instrumentation program is clear, because movements in reinforced residual soil mass would not be expected. In this case, these continuing displacements were caused by further excavations in a neighboring construction site (Lima, 2007).

Tensional loads in the strain-gauged nails were registered from March 2004 to July 2006. Typical results are presented in Figure 7 for the first strain gauge at 3m from the slope face, at the upper nails from each instrumented section. The results also show a progressive increase of the mobilized tension during the evolution of the excavation. A tendency for load stabilization is noted after the end of excavation.

Figure 8 shows a typical plot of bending moments M measured at the same nail (G07), at a position 3m distant from the excavation face. Strain resulting from nail bending was considered small (less than 10% of maximum to be resisted by the steel bar).

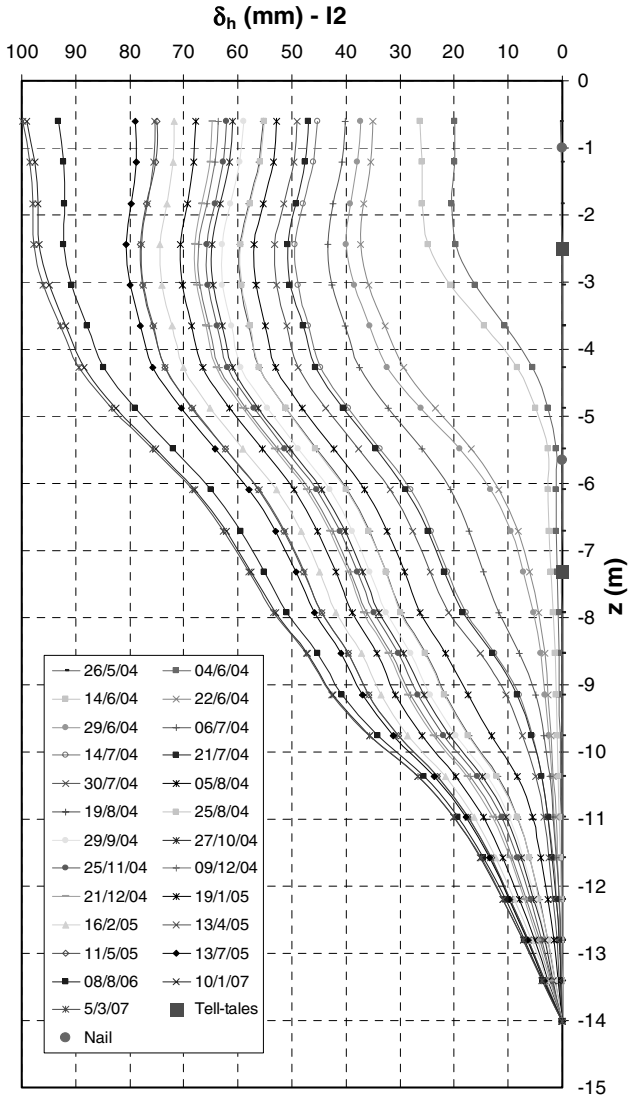

Figure 6. Horizontal displacement profiles from inclinometer I2.

5 CONCLUSIONS

Instrumentation programs are recommended for monitoring the behaviour and ensuring the safety of soil excavations.

This paper presented details of instrumentation procedures at a 40m nailed excavation in residual soil. Soil displacements and nail mobilized tensional loads were registered during the several excavation stages. Horizontal displacements from tell-tales were noted to agree reasonably well with inclinometer readings. The strain gauges glued to steel bars proved to be very efficient for indicating tensional loads along the nails. Progressive loads and displacements in the nailed mass were shown to occur during and even after the excavation works.

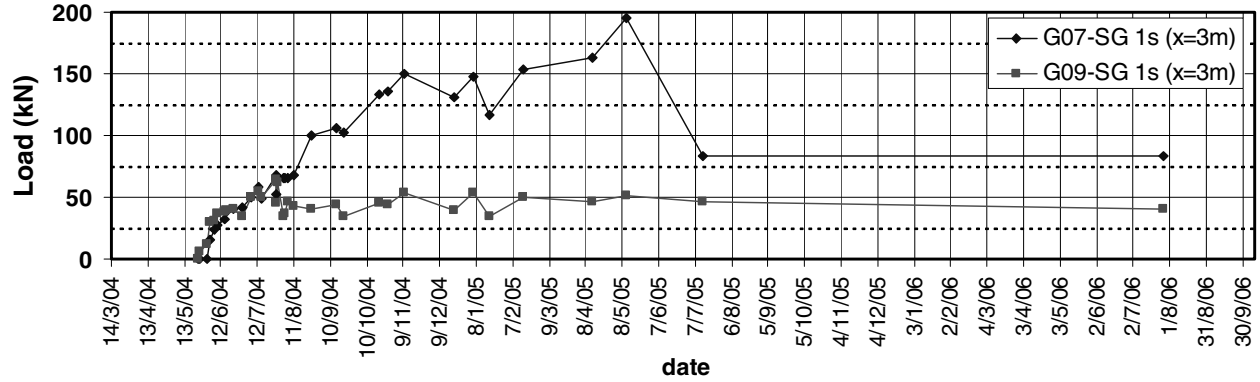

Figure 7. Tensional load in upper nails G07 and G09 at 3m from slope face in central instrumented sections.

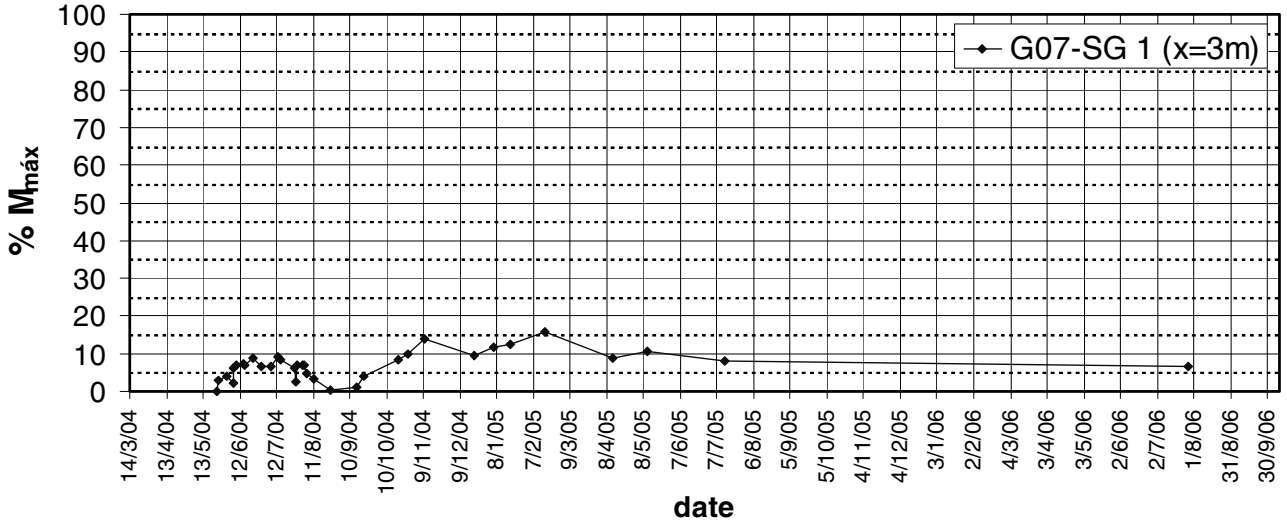

Figure 8. Bending moments in nail G07 at 3m from slope face.

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