ANALYSIS OF THE PERFORMANCE OF TIE-RODS ANCHORED IN COHESIVE SOILS, THROUGH THE NUMBER OF INJECTION STAGES

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Abstract

One of the major difficulties related to containment works projects through the use of prestressed anchorages is in determining the load capacity of the ties related to the reinjection criteria. The geotechnical properties used in the project do not always represent the reality for the type of soil in the worked region, making the amount of cement injected inaccurate. The soil-bulb load transfer, in retaining works, is dimensioned by methodologies that do not fit the reality of the soil parameters in loco, making it essential to carry out tests on tie rods to prove their performance and in terms of meeting the specifications of project. This study aims to analyze the load capacity in prestressed anchorages of a cable-stayed curtain through the number of injection phases, located in a slope stability work in the municipality of São Miguel Arcanjo, southwest of São Paulo. Depending on the characteristics of the massif, the anchorages made using steel cords were evaluated through the injection pressures according to the soil resistance and the number of reinjections, verifying their performance according to receiving tests according to the ABNT-NBR 5629 standard. (2018). Evaluating that for each type of soil and for each type of work to be carried out there is an injectability limit, and the best limit should be compatible with the mechanical resistance of the soil to which the tie will be executed, demonstrating that the injection in a single phase can be adopted for solids with high support capacity, making the technical-economic relationship of the work possible through the number of injections.

Keywords: Ties, grout injection, slope stabilization, qualification test.

1. Introduction

The first paragraph under each heading or subheading should not be indented. The main body text alignment is fully justified, single (or 12-pt) line spacing, and font type Times New Roman 10-pt.

The subsequent paragraphs should have a five-space indentation. The fully justified text should be formatted in two parallel columns, each 8.9 cm (3.5 inches) wide, and separated by a space of 1.27 cm (0.50 inches). All margins should be 1.91 cm (0.75 inches).

Soil reinforcement comprises a set of techniques with the aim of improving its mechanical or physical properties, through the establishment of inclusions that act by traction, compression or bending. Among these techniques are driving, tie rods, micropiles, and excavated piles [1].

One of the greatest difficulties in using containment techniques to guarantee the stabilization of slopes and excavations is to present a viable technical-economic alternative. However, due to the specific conditions under which they were developed, the results do not always represent the reality for the type of soil in the region being analyzed, making the costs high. The choice of containment to be executed on a slope must take into account the geotechnical aspects, dimensions of the slope, effectiveness of the chosen technique and mainly the costs. Works involved by large movements of soil, often use containment methods that involve the application of anchorages through the use of ties.

Despite the widespread use of this technique in Brazil, there is a limited number of studies carried out on the method of execution and establish the amount of grout injected per phase in each manhole valve. It is clear that it is difficult for an engineer designer to design a craft service, however, once the philosophical principle is established, basic design parameters can be established, taking into account previous experiences, it is easy to estimate the treated area, the spacing between the holes, the distances between the valves and the amounts and pressures per time or phase [2].

Studies conducted by [3] and [4]) showed that the stability of a containment with use of anchors is studied in its limit state, being the mechanism responsible for the load transfer and restriction of the movement of the soil mass, is the shear strength (qs) and load capacity. The most approximate estimate of the shear strength of soil ties is obtained through semi-empirical formulations available in the literature [4-9]. It can be noticed that the special containment works in Brazil are often dimensioned by methodologies that are not satisfactorily suited to the reality of the national soil, causing projects that do not meet the basic paradigm of engineering which is: "enable the execution of economic and safe works" [9].

The real rheological behavior of the anchorages is obtained through tests before the execution of the ties, from receiving, qualification and/or basic tests established by [8]. The methodology of execution, type of tie, hole diameter, water/cement factor, execution time, injection methodology and injected volume, represent the reality of the behaviour of the anchors with respect to their load capacity. According to [10] the protension of this element when anchored in a suitable part of the soil mobilises a resistance reaction, whose load is transmitted to the containment structure by the part known as the tie head, being the anchorage the part responsible for the load transmission to the head occurs by the free section.

The residual load verification tests in tie-rods are important to keep the curtain wall containment structures anchored and are performed in 15% to 20% of the tie-rods. However, the distribution of this test, besides being random, can increase when the results of the initial tests demonstrate loss of load for ties in a certain region of the structures [11].

The present work aims to perform through a slope stabilization work by curtain wall, the contribution of verification of the performance of ties through the volume of grout injection to create conditions of resistance that allow its anchorage, disregarding the need for several stages of reinjection, proving its mechanical behavior through the interaction between tie and soil based on the receipt tests established by [8]. Considering the experience of the executor, the monitoring of the execution and the analysis of instrumentation, conditioning elements in defining the project for the number of stages of injection, enabling a technical-economic relationship of the work.

2. Material and Methods

2.1 Characterization of the work

The work located in the municipality of São Miguel Arcanjo southwest of São Paulo, extending over 930.34 km², with an average altitude of 660 meters above sea level, the curtain is located in the geographical coordinates of 24˚02'22" south latitude and 48˚00'45" west longitude, held within the Carlos Botelho ecological park (Figure 1).

Figure 1. Location of the study area.

With a length of 35 km the Park Road was built next to the ecological park, in order to ensure environmental preservation and sustainability of the region, but due to several sections resulting from landslides, ecotourism in the region was harmed (Figure 2a), and the work was considered emergency criteria. The slope stabilization was performed along the environmental reserve in the assessed risk sections, through the technique of curtain wall (Figure 2b) associated with drainage system.

(a) (b)

Figure 2. (a) General view of slippage, (b) General view of hillside recovery with curtains.

2.2 Geological characterization

The region of São Miguel Arcanjo involves by complete area of the municipality the Upper Paranapanema Basin, being represented by rocks of the Group Suite Granitic Synthectonic, Açungui and Post-Tectonic, Itararé Group and Cenozoic Deposits. The rocks of the Pilar Complex of the Açungui Group occur in the south of the municipality and are represented by phyllites, quartz phyllites and metasediments with subordinate intercalations of mica schists (PSpF) and quartzites and by dolomitic and calcitic marbles (PSpC) [12].

The Synthetic Granitic Suite is represented by rocks of the Cantareira facies (PSyc) and it happens limited to a smaller portion in the municipality, in contact and to the west of the rocks of the Pilar Complex. According to [12] it exposes para-autochthonous and foliated, allochthonous bodies, fine to medium grained, frequent porphyritic texture, partially concordant contacts and granodioritic to granitic composition. The Post-tectonic Granitic Suite appears reserved to an area in the center-south of the municipality, displaying rocks of the Itu Facies (€Oyi), which are granitic to allochthonous granodioritic bodies, isthropos, fine to coarse grained, with sub-hydiomorphic and hypidiomorphic granular texture [12]. The rocks of the Itararé Group are dominant in the area of the municipality and consist, above all, of sandstones with variable granulation, from fine to conglomeratic, argillaceous, occurring also significant packages of diamictites and pelitic sediments, presented by grey siltstones, shales and rhytmites [13]. They also have colluvial deposits that were laid down between the Pliocene and Pleistocene, which are made up of sands with a clay matrix; limonite and quartz gravels in the foundation [14].

2.3 Geotechnical characterization

The subsoil of the slope area where the cable-stayed curtain will be installed is located in a colluvium region, basically consisting of two stratigraphic units, following a profile with a thin soil layer superimposed on rocky material.

According to the results of the soundings performed at the crest of the cable-stayed curtain, the soil layers are made up of alternating successions of clay with the presence of fine and medium sand as well as lightly sandy silt, presenting an average thickness of 2 to 4 metres with NSPT varying between 15 and 25 blows. Followed by a layer of alteration soil with sandy clay characteristic with presence of pebbles and boulders, ranging from 4 to 6 meters thick with NSPT of 25 to 30 blows, indicating presence of impenetrable material from 6 meters.

The thin layer of residual soil of São Miguel Arcanjo, in general is rich in fine and medium silty sand very compact with presence of mica, or clayey silt of hard to very hard consistency with boulders, Figure 3 indicates the local geological characteristics.

Figure 3. Geological characteristics of the area of execution of the cable stayed curtain.

2.4 Execution of the Anchored Curtain

After the slips all debris mass was removed until the stable soil layer, the ties were executed in a downward manner in two lines with a 15 degree inclination in relation to the final lay out of the slope cut at 90º, and 16 m long (Fig. 4a), 8 m anchored and 8 m free with 4 ropes of 12.7 mm, with 16 manhole valves in the anchored section spaced every 50 cm (Fig. 4b).

The drilling was performed with machines supported on 4 m berms (Figure 4c), with cleaning of the hole using compressed air to avoid its closure and environmental damage (Figure 4d), because the initial test drilling with water caused the hole to close, contributing to the increase of the existing saturation of the rock mass, promoting sliding of the slope, making it impossible to insert the tie-rods, besides the mud generated during drilling damaging the environment through the springs and native vegetation.

Figure 4. (a) Tie line, (b) overview detail of tie line, (c) detail of machine supported on berm, (d) drilling with compressed air.

After the execution of the tie-rods, root-type piles were executed as foundations of the cable stayed curtain (Figure 5a), and the original geometry of the slopes were maintained, leaving about 3 m of free stretch of tie-rods, incorporated during the concreting of the panels (Figure 5b), the drainage system behind the curtain were interconnected to barbacans (Figure 5c), The drainage system behind the curtain was connected to barbs (Figure 5c), enabling the removal of water from the embankment by throwing and vibrating medium coarse sand to reconstruct the roadway (Figure 5d).

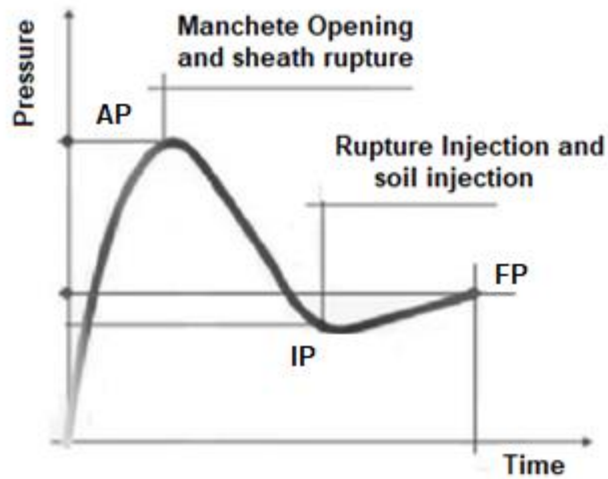
(a) (b) (c) (d)

Figure 5. (a) execution of the root pile, (b) general view of the ties incorporated into the curtain, (c) detail of the drainage system, (d) geometry of the track reconstituted with sand.

The grouts commonly used to execute tension specimens are basically composed of cement and water, where eventually to improve their stability and injection characteristics, some type of additive (accelerator or retarder) can be added depending on climatic conditions. Tests conducted by [15] show that grouts can vary their strength slightly due to the various brands of cement and types of additives. The main factor that affects the properties of the injections is the w/c (water/cement) ratio, because excess water causes exudation, which reduces strength, increases shrinkage, porosity and decreases the adhesion of the anchors to the soil. The analysis of the grout injection performance of the tie-rods were performed according to the recommendations of [4] and [16, which is based on the geological behaviour of the rock mass, and through technical procedures such as: injection lines, hole spacing, injection pressures, grout types and grout refusal criteria. For each grout type and for each type of work to be done there is a grout injectability limit, the grout capacity to penetrate the medium to be injected, and the best injectability must be compatible with the mechanical resistance that the grout must offer. According to [17] the injection pressure depends on the permeability of the ground, the opening of the fissures, the flow viscosity and the number of phases that generate a pressure gradient. This gradient can be called the "soil improvement gradient", that is, increments in the capacity of the soil to react to the pressure during the various injection phases at each point.

The anchorage bulb is responsible for interacting with the soil by transmitting the tensile stress, formed by grout injection under pressure and fixed or anchored in the stable region of the massif. According to [3] the load capacity of the anchorage is closely related to the geometry, configuration and size of the anchorage bulb, elements with direct connection to the execution methodology. The type of plug used and injection pressure can generate uniform bulbs through a single injection phase with low pressure or in root shape with high injection pressure and through reinjections. The irregularities and fractures of the soils cause the cement cream to penetrate resulting in bulb enlargement and rooting, with possible generation of hydraulic fracture in points of greater fragility. According to [18] the grout pressure application to fill the voids compresses the ground surrounding the tie until there is a hydraulic rupture of the soil, generating fissures through which the grout will infiltrate. For the execution of the injections, the cement grout preparation scheme was performed through a central near the test area, through a high turbulence mixer equipped with turbine, with minimum rotation of 1,700 rpm, capable of preparing cement grout in sufficient quantities to supply the injection pump providing adequate homogeneity to the mixture. The evaluation of the number of injection phases was performed in 21 tie bars, submitted to sheath injection and different phases according to Table (1), with grout factor a/c 0.5 and mechanical resistance at 28 days with values between 25 and 28 Mpa. The injection pressures and grout volume absorbed for all the gate valves were monitored through a pressure stabilizer installed near the injection center, depending on the grout behavior regarding the injectability in the rock mass, the opening pressures (AP) varied from 25 to 45 kgf/cm2, and injection pressures (IP) averaged 30 kgf/cm², thus the number of injection stages was performed according to the injectability of the soil around the anchors, carried out after a period of 24 hours (Figure 6a). The interruption of the injection stage for each headline valve was performed when the values of the final pressure (FP) exceeded the values of the injection pressure (PI), enabling the development of the anchorage bulb (Figure 6b).

(a)



(b)

Figure 6. (a) General view of tie rod injection, (b) Detail of tie rod injection pressure.

Table 1. indicates the consumption and pressure parameters verified on site during injections.

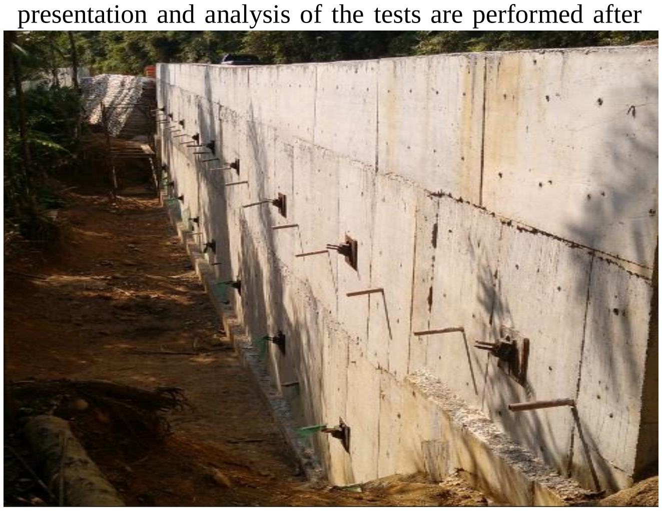
Injection phases	Number of tie rods	Cement consumption (kg)	Opening pressure (PA) (Kgf/cm²)	Injection pressure (PI) (Kgf/cm²)
Sheath	21	500 a 600	0	0 á 5
1st Phase	7	1200 a 2400	25	20
2st Phase	7	600 a 1200	35	25
3st Phase	7	600 a 800	45	40

3. Field tests performed

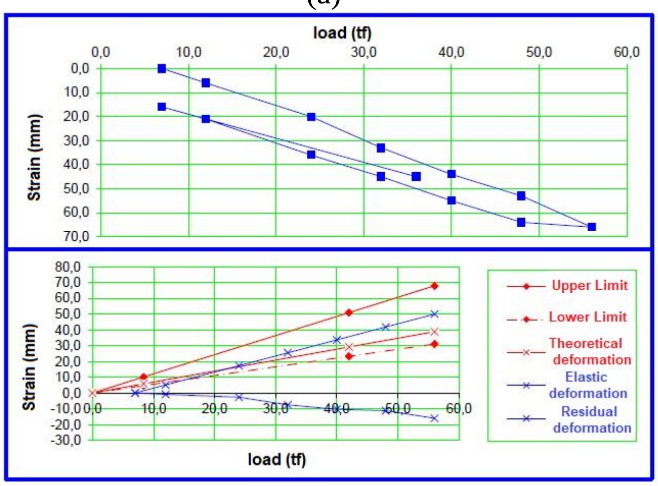
After performed the last stage of tie-rod injection, waiting the period of seven days as stipulated by the standard [8] were performed post-tensioning tests in order to verify the efficiency in the implementation of the tie and test their suitability to receive the work load (Ft) provided in design.

The purpose of the tests is to prove its performance in terms of meeting the design specifications, avoiding possible situations of risk in the stability of slopes.

According [8], to evaluate the load capacity and behavior of the tension specimens, acceptance tests were performed with a maximum load of 1.40 (Ft), in a curtain with 21 tension specimens according to Figure (8 a), with a working load of 40 tf, evaluated in batches with different stages of injections as indicated in Table 1. The receipt test is made from the application of a cycle of pre-defined loads and the readings of displacements of the tie head during loading and an unloading in the last stage of the cycle. The presentation and analysis of the tests are performed after plotting two graphs. The first refers to the applied loads and total displacements and the second to the displacements divided into elastic and permanent, being the acceptance of the ties verified mainly through the results referring to the maximum stabilized load and the friction mobilized in the anchored section. Through the data from the qualification test were plotted graphs of loads x displacements, the maximum displacement of the head must be located between the upper and lower lines as prescribed in standard [8]) indicated in Figure 8 (b, c, d). For the tests to be accepted, the head displacements should be less than 1 mm at intervals of 5 minutes for sandy soils and 10 minutes for clayey soils, when applied the maximum load.



(a)



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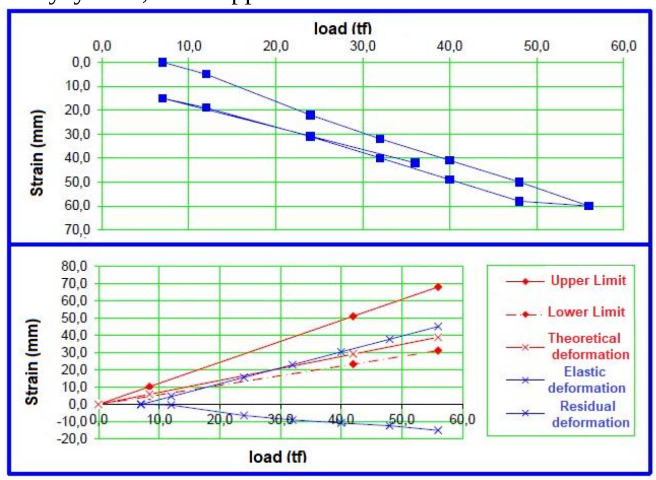

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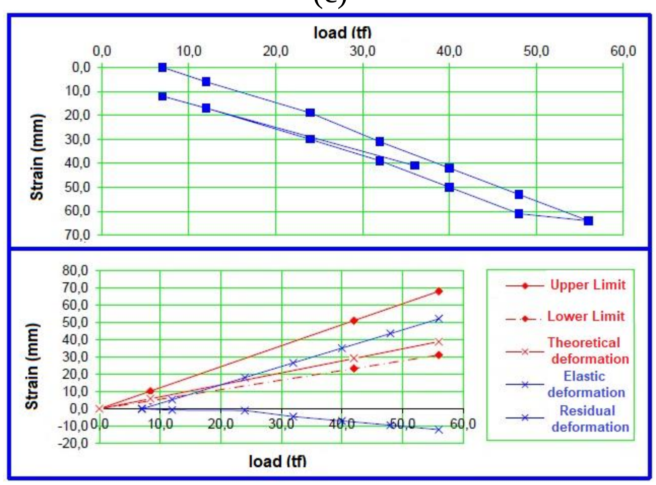

(d)

Figure 8. (a) General view of the curtain of tested tension specimens, Reception tests tension specimens: (b) 1st injection stage, (c) 2nd injection stage, (d) 3rd injection stage.

4. Analysis of results

According to the graphs obtained from the receiving tests, it can be seen that the influence of reinjection in successive stages for soils with clay and silty characteristics, indicates that there is a less significant influence on the performance of the ties performed with high pressures and successive stages for residual soils and/or alteration with strength index NSPT greater than 20. According to studies conducted by [19] for soils of medium consistency or compactness only the primary and/or secondary stages8 are necessary.

All the injected ties with different injection and cement consumption stages performed in the curtain wall met the recommendations of [], within the upper and lower limits.

Studies conducted by [3] and [7] warn that depending on the soil type, reinjections do not necessarily characterize an increase in load capacity. According to [4] the improvement of the load capacity through the technique of increasing the number of injections, is directly related to soils of low strength as embankment, soft soils and high permeability, contributing in changing their parameters such as cohesion and friction.

The determination of the injected cement volume depends on the local characteristics which is based on the geological behaviour of the rock mass, and through technical procedures such as injection lines, hole spacing, injection pressures, type of mix and refusal criteria of the cement grout in the rock mass.

According to [20] the search for increasingly more technically and economically efficient scaffold structures should be carried out through the application of quality control tests in construction phases and not only for the confirmation of the performance of the anchorages, i.e., it is necessary to apply in situ tests for the calibration of the correct load capacity and sizing of the anchored bulb in the region of the soil of implantation of the structure.

Regarding the technical-economic issue that involves the use of tie-rods, this service, as it is a specialized activity, requires the execution to be done with specialized materials, teams, equipment and control, increasing the costs of the anchorages. Through the control of the method of injection in phases it is possible to achieve an analysis of the cost-benefit ratio, representing a saving in the amount of cement in the works of about 60%, not performing the 2nd or 3rd phase of injection for soils of average consistency or compactness, in addition to enabling the execution time contributing to the schedule of the work.

5. Conclusions

The qualification tests allow verifying the reliability of the performance of the tiebacks after their execution, besides allowing design adjustments during the execution. In function of the conditions verified during the tests and of the grout behaviour regarding the injectability in the rock mass, the pressures can be reduced as well as the injection stages according to the permeability of the soil around the anchorage.

In order to maintain the contribution of the tie-rod technique in shear slopes, guaranteeing its low cost, it is necessary to maintain the guidelines according to the characteristics of the site, which is based on the geological behaviour of the rock mass and through the technical procedures such as injection lines, spacing between holes, injection pressures, injected volumes, grout types and grout refusal criteria.

The groups of tests performed have a good representativeness, especially for string ties performed in cohesive soils with values of penetration resistance index NSPT higher than 20, with injection control with manhole valves spaced every 50 cm and injection with double plug (from the bottom of the hole to the tie head). Demonstrating that for soils of medium to hard consistency, the reinjections do not necessarily characterize an increase in the load capacity of the tension specimens.

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