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The practice of testing ground nails

La pratique des essais de clous

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ABSTRACT: The soil nailing construction technique is often used to stabilise a ground mass by installing reinforcing elements (nails). The European Standard EN 14490:2010 defines general principles for execution, supervision, testing and monitoring of soil nailing. This paper presents tests results obtained in several ground nails executed in recent geotechnical works. These tests were carried out in sacrificial nails, before and during the works. As shown in this paper, the execution of the nails, the test system and test procedures affect their results quality. Thus, a critical analysis of the tests results is performed to assess the behaviour of the ground nails, framed by EN 14490:2010, in accordance with the design and contract specifications.

RÉSUMÉ: Le clouage est une technique de construction utilisée pour améliorer la stabilité d'un massif du terrain par la mise en place d'éléments de renforcement (clous). La norme européenne EN 14490:2010 établit les principes généraux pour la construction, les essais, le suivi et les contrôles d'exécution des ouvrages avec clouages. Cet article présente les résultats d'essais obtenus sur des clous exécutés lors de travaux géotechniques récents. Ces tests ont été réalisés sur des clous sacrificiels, avant et pendant la construction. Comme s'expose dans cet article, l'exécution des clous, le système de test et les procédures des essais affectent la qualité des résultats obtenus. Ainsi, une analyse critique des résultats des essais est réalisée afin d'évaluer le comportement des clous, encadrée par la norme EN 14490:2010, conformément aux spécifications du projet et du contrat.

Keywords: Nail; load test; proof load; sacrificial nail.

1 INTRODUCTION

Ground nails mobilise frictional forces along their entire length, which contributes to improve the ground stability if the stability conditions are adverse.

The stability is achieved by inserting reinforcing nail elements into the ground. To validate the ground nail resistance, to assess their behaviour or design considerations, nail load tests shall be carried out.

The test procedures and locations of a nail test shall be validated. Previously, the tests program shall be defined, all the elements presented, evaluated, and confirmed. The contractors equipment and their calibration certificates shall be evaluated and identified for each test.

This paper presents the results of sacrificial nail tests, obtained in recent geotechnical works.

The sacrifitial nails were instaled in the same way as the production nails, only to establish the pullout capacity, and do not forming a part of the ground nail structure.

Based on the collected data, recorded in the tests sheets, this paper presents tests results analysis in accordance to EN 14490:2010 specifications. Conclusive synthesis and recommendations are presented.

2 GROUND NAIL LOAD TESTS

The EN 14490:2010 recognizes two distinct types of static load tests: i) in sacrificial nails; and ii) in production nails. Testing requirements are stated in EN 14490:2010.

Normally, a sacrificial nail test involves loading the test nail to failure, or to the characteristic value of the resistance anticipated in the design.

It is essential that the test nail be axially loaded. The facing system or the load test reaction system cannot influence the test results.

Static load testing can be used for a variety of purposes, including to verify the nail ultimate bond resistance, used in the design, and to demonstrate the satisfactory nail performance.

3 EQUIPMENTS AND PROCEDURES

3.1 Layout of the nail test system

In the nail load tests presented in this paper, the load was measured directly, with a load cell, and indirectly, with a calibrated pressure gauge monitoring the pressure of the hydraulic stressing jack (Figure 1).

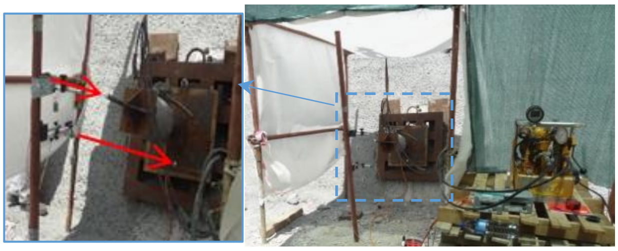

Figure 1. General view of a ground nail load test layout.

To control the bar and wall movements, the displacement monitoring system was installed in an independent support. The jack extension was also monitored.

The equipment has been previously calibrated.

3.2 Tests programs and procedures

The test programmes were designed in accordance with EN 14490:2010 requirements, considering two cycles, with the first cycle up to the load of $0.5P_p$ and the second up to the proof load, P_p.

The sacrificial nail test intends to verify the ultimate pullout resistance and creep characteristics of the nail. Concluded the load test program, when the bond length had not reached the failure, it was recommended a second load test phase to evaluate the nail load capacity (according EN 14490:2010, C.3.3.3). The second program test phase presented in this paper, was defined considering the tensile capacity of the nail bar, which consists in a single steel bar with 25 mm of diameter. In the geotechical works presented, the nails bond length varies between 2 m and 8 m.

The presented ground nailing work was done in 71 granitic slopes stabilization works with various weathering levels and joint patterns (Figure 2). These works had technical assistance from the paper author.

Figure 2. Examples of slope stabilisation in granitic rock masses that have different weathering levels and joint patterns.

4 TESTS RESULTS

45 sacrificial test nails have been done but, in this paper, only five examples of test results are presented, represented by diagrams of the displacement evolution with applied load. The results are presented for two different monitoring systems: (i) load cell and bar displacement (Cell-Bar); (ii) load pressure gauge and stressing jack displacement (pressure gauge-jack extension). These diagrams also present the evolution of elastic and plastic displacements with load of the reinforcing element ($\delta_{e;}\,\delta_p$), the datum load (P_a) and the proof load (P_p). Figure 3 to Figure 7 represent the results of the in-situ sheets data tests of the contractors' reports.

The theoretical value of the elastic displacement of the bar (δ_{et}) is obtained by:

$$\delta_{et} = \frac{\Delta P L_{lt}}{E A_t} \qquad (1)$$

considering E=200 (kN/mm^2); the nail steel cross section A_t= 490.87 (mm^2); the total de-bonded length $L_{lt}=L_l+L_e$ (mm); and the theoretical value of the difference between the proof load (P_p) and the datum load (P_0), as in the program test ($\Delta P=P_p-P_0$).

5 REQUIREMENTS

It is necessary to ensure that the nail has the pullout capacity to support the P_p and comply with the standard EN 14490:2010 criteria, namely:

a) In a sacrificial nail test the creep rate (k_s) must be less than 2 mm at P_p unless the design defines a lower value.
b) In a load test, the extension measured in the nail head, at P_p, is not less than the expected elastic extension (δ_{et}) for the nail de-bonded length.

The quality of the data field registrations, a correct equipment installation and an adequate test program are primordial to achieve the test goal.

6 RESULTS ANALYSIS

6.1 Monitoring with redundancy

Monitoring with redundancy is not a standard requirement of the EN 14490:2010. However, the redundancy of recording loads and displacements data results in important benefits, namely the possibility to clarify doubts and confirm aspects associated with the nail behavior, if necessary.

Figure 3 and Figure 4 present the values obtained in the same test for two diffent systems. One of the systems consists of monitored the values by the load cell and the bar displacements gauge. The other system is composed by the pressure gauge pump and by the extension jack, to monitor the load and displacement, respectively.

The data obtained with both systems shows a diferent mechanical behaviour (Figure 3), namely a diferent elastic behaviour in each cicle. However, in Figure 4 the behaviour diferences are smaller.

Other advantage of the redundancy, is the possibility to conclude the test if a device has problems during the test.

6.2 Creep rate (k_s)

The creep rate, k_s (mm), is defined as (eq. 2):

$$k_s = \frac{d_2 - d_1}{log_{10}(t_2/t_1)} \qquad (2)$$

where d_1 and d_2 are the measured displacements (mm) at time 1 and 2 (minutes), respectively.

The value obtained for k_s, in the successful nail tests, was smaller than 0.5 mm, So, the creep rate respects the statements of EN 14490:2010.

6.3 Mechanical behaviour

The results obtained on the nail nº4 indicate an adequate mechanical response (Figure 3a) and Figure 4), satisfying the design and standard EN 14490:2010 requirements.

In the test nail nº3b and 4.1 (Figure 5a, and Figure 6a, respectively) the bond failure was reached. In these cases, the nails do not have lateral resistant capacity to support P_p. So, the test does not meet the conditions to be considered valid, the procedures of the nail construction shall be reviewed and / or the design reanalysed.

The nail nº3b reached the failure in the beginning of the 1st cycle (Figure 5a), and also presents a high deformability from the datum load, P_a, which indicates that the nail has: (i) execution deficiencies; or (ii) the bond length may be insufficient; or (iii) the ground, eventually, does not have the design resistance characteristics estimated for that location.

However, in the case of the nail nº 4.1 (Figure 6a), given the value reached, the failure could have occurred in the sealed area or in the nail steel bar.

At the beginning of the nail nº8 test (Figure 5b) signs of test execution deficiencies were shown. These anomalies could be related, amongst other possibilities, to the equipment assembly, with the displacement's measurement, for instance due to movements of the fixed reference, or the occurrence of gaps or friction, which were not eliminated before the beginning of the test. These deficiencies outcomes in difficulties that do not allow the reliable determination of displacements and, consequently, the determination of the corresponding value of k_s, and / or the evaluation of the nail mechanical behaviour, namely the accurate value of the permanent and elastic displacements, for example, for the test nail nº8 (Figure 7a) those displacements do not comply the EN 14490:2010 requirements.

The results obtained in the nail test 4.2 (Figure 6b), show a pronounced hysteresis, particularly in the 2nd cycle. This hysteresis may be related with the prestressed system or with the nail mechanical behaviour, as it only has 2 m of bond length. However, it appears to have the capacity to withstand the proof load and the test results (Figure 7b) fulfil the EN 14490:2010 requirements.

Deficiencies are often observed in nail tests. In these cases, the tests do not exhibit quality, have unsuccessful results and they do not meet the requirements to consider the ground nail work valid.

In this context, it should be noted that the test quality depends on the previous preparation of the operational procedure for carrying out the nailing works and their tests, the previous equipment calibration, and their approval, as well as on the workers quality, equipment installation control, data registration quality, amongst other aspects.

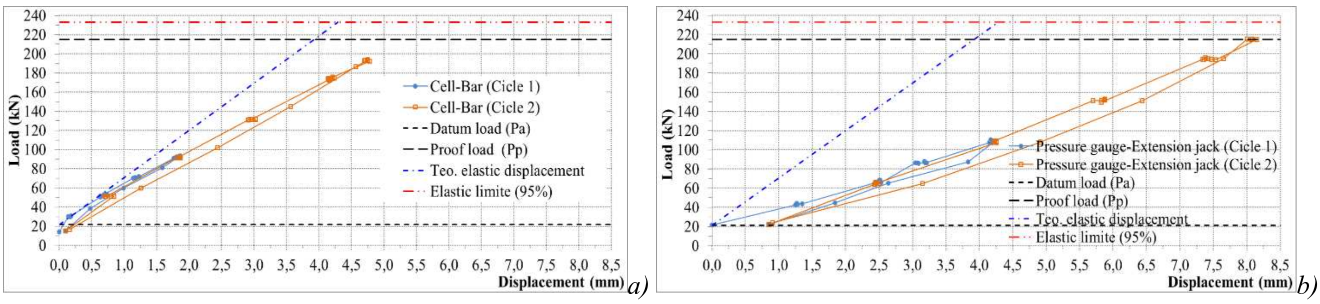

Figure 3. Nail nº4. Evolution of the displacements with load: a) cell-bar; and b) pressure gauge-jack extension.

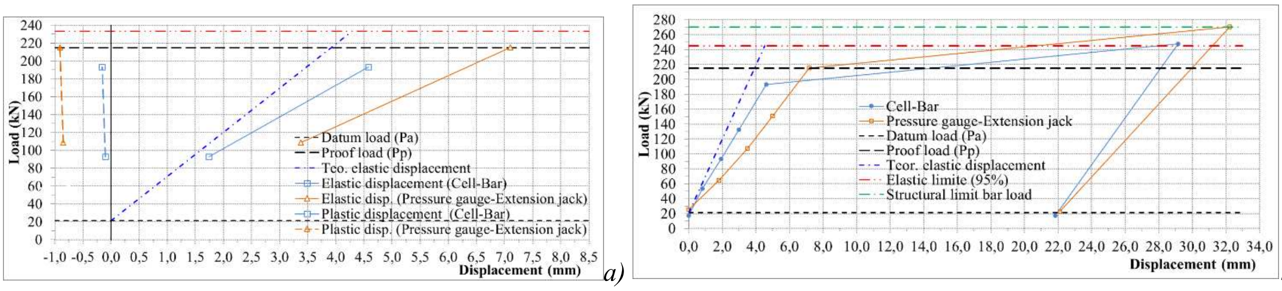

Figure 4. Nail nº4. Results obtained in both monitoring systems. Evolution of the plastic and elastic displacements with load (a), and evolution of the total displacement with load, in the 2^{d} test phase (b).

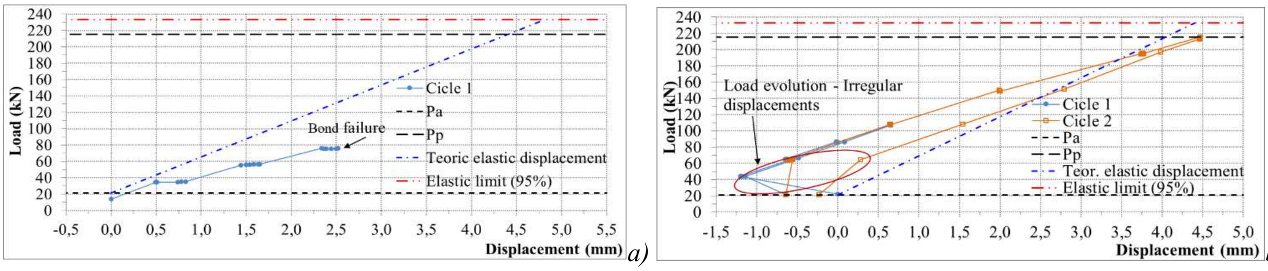

Figure 5. Evolution of the displacements with load, of the nails nº 3b (a) and nº 8 (b).

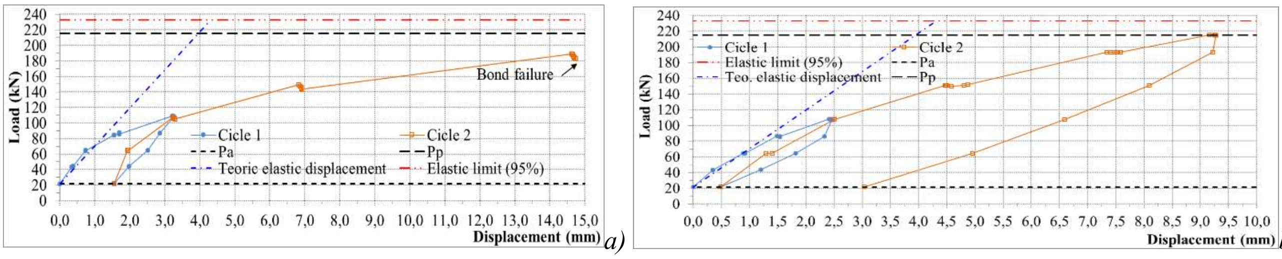

Figure 6. Evolution of the displacements with load, of the nails nº 4.1 (a) and nº 4.2 (b).

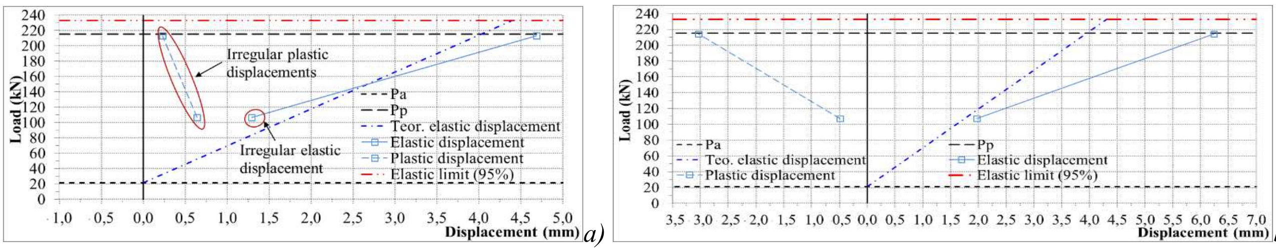

Figure 7. Evolution of the plastic and elastic displacements with load of the nails nº 8 (a) and nº 4.2 (b).

7 CONCLUSIONS

Some tests results do not comply the EN 14490:2010 criterions, either due to the occurrence of permanent displacements manifestly greater than the elastic ones, or by because of the abnormally reduced values of elastic displacement and, also, because there are tests where negative permanent displacements were recorded. These cases may be related to anomalous circumstances, nail failure, tests lack quality, which present inconsistent data, such as displacement reduction as the load increases, among other events. To allow to understand the nail behaviour, the tests quality should be warranted.

The creep values (k_s), like expected for granites, was low so, regarding the creep behaviour, they are not constraints in the geotechnical areas where tests results comply the EN 14490:2010 requirements.

In each ground conditions, the sacrificial nail test intend to allow to: i) validate the construction method; ii) ensure that the required nail design capacity is guaranteed; and iii) ensure that the nails mechanical behaviour is adequate. The production nail test allows to demonstrate that the nails installation methods and the ground conditions encountered result in satisfactory nails behaviours, at the proof load.

It is clearly relevant the necessity of doing tests in ground nailing works, either in soil or rock.

REFERENCES

EN 14490:2010 (2010). European Committee for Standardization. Execution of special geotechnical works - Soil nailing. CEN, Brussels.