

Tensile tests on vertical and inclined anchors for high voltage electrical transmission towers in Uruguay

Ensayos de tracción en anclajes verticales e inclinados para torres de transmisión eléctrica de alta tensión en Uruguay

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ABSTRACT: The Foundations Quality Control Laboratory (LCCF) of the Universidad de la República (UdelaR) conducted tensile tests on several vertical and inclined anchors to validate their individual load capacity. All the anchors evaluated are part of the foundation bases of the electrical power transmission towers built as part of the infrastructure works for the connection of the high-voltage lines between Uruguay, Brazil and Argentina. To perform these tests, procedures and protocols were previously established, considering the technical specifications required by the contractor and the reference standards. Drawings were also produced for the correct assembly of the reaction beams, instrumentation, and other components of the system. During the tests, load and unload cycles were staggered and the displacements obtained were recorded at the top of the grout and at two points on the steel bar. The arrangement of the instruments and the visual inspection made it possible to determine the anchor failure mode, for the cases where failure was reached. This article presents the different reaction devices used and the main results obtained in the tests, with the general conclusions of the works.

KEYWORDS: tensile load tests – anchors – reaction devices

1 INTRODUCTION

Since 1995, the LCCF of the Engineering Faculty of the UdelaR has conducted research and consultancy in the area of foundations, including studies of piles subjected to compression, tensile and horizontal loads, and the study of the effects of concrete compaction on piles.

Throughout its history, the LCCF has worked on tests of high-voltage transmission towers foundations belonging mainly to the national electricity company, the National Administration of Power Plants and Electric Transmissions (UTE). The first work consisted of the study of small diameter piles (from 0.20 m to 0.30 m), vertical and inclined, with compacted and uncompacted concrete, subjected to tensile stresses (Gutiérrez et al. 1997). For this purpose, systematic load tests were conducted until failure to predict the bearing capacity of piles in clayey soils of Libertad and Dolores geological formations, characteristics of southern Uruguay (Gutiérrez et al. 2000).

Based on these early works, the LCCF team conducted tensile tests on vertical and inclined ground anchors to validate their individual load capacity. Ground anchors are steel tendons or strands secured in the ground by grouting. They are used to provide uplift resistance or lateral resistance to transmission towers and other structures (Kim 2003). Anchor tensile tests can be classified into two categories: qualification tests and acceptance tests. The qualification test is performed on an anchor to check its behavior in a given type of soil or rock, while the acceptance test is performed to check the load defined in the project and the performance of the anchors in a construction site (ABNT NBR 5629 2018).

Most of the anchors evaluated by the LCCF are part of the foundation of the electrical transmission towers that were built within the high voltage line interconnection between Uruguay, Brazil and Argentina. Procedures and protocols were previously

established considering the technical specifications required by the contractor and the reference regulations. Drawings were also prepared to assemble the reaction system, the loading system (hydraulic cylinder, oil pump, pressure gauges), the displacement measurement system (dial test indicators) and other components of the test system. The test setup is similar to that presented in other documents, such as Kim (2003) or FHWA-IF-99-015 (1999).

During the tests, loading and unloading cycles were applied in a staggered manner, and the displacements obtained at the anchor head were recorded. In some cases, the displacements of the steel bar between the upper surface of the grout and its free end were also recorded. The arrangement of the measuring instruments and the visual inspection allowed to identify different failure modes. According to Littlejohn & Bruce (1977), those are mainly four: failure within the rock or soil mass, failure of the soil-grout bond, failure of the soil-tendon bond, and failure of the steel tendon or top anchorage.

The different test devices used and the main results obtained for some study cases are presented: tests on 500 kV High Voltage Lines Uruguay - Brazil (San Carlos - Melo) for the company Techint, tests on 500 kV High Voltage Lines Melo - Tacuarembó for the company Saceem, tests on 500 kV High Voltage Lines Tacuarembó - Chamberlain, Chamberlain - Salto Grande, for the company CEMEC, tests on 150 kV High Voltage Line Minas, for the company Teyma.

2 HIGH VOLTAGE LINE 500 KV URUGUAY - BRAZIL (SAN CARLOS - MELO) – SITE 1

Various tests were conducted for UTE to approve brace anchors for towers and vertical anchors for foundations of self-supporting transmission towers in the 500 kV High Voltage Line project built between the San Carlos Substation and the border with Brazil, in Uruguay.

2.1 Braces

For the approval of the brace anchors, two types of anchors were installed: solid bars (installed in locations 219 and 242) and self-drilling injected anchors (installed in locations 219, 287 and 302).

The anchors were built in two types of rock and in cohesive soils. The anchor bars had diameters between 29.6 mm and 40 mm, with anchor lengths between 4.20 m and 8.20 m.

The tests reached a load of 550 kN, corresponding to the design load increased by 30 %. The test procedure consisted in applying an initial load of 10 % of the design load. Then four load steps were applied at 40 %, 70 %, 100 % and 130 % of the design load. On each step the load was maintained for 1 minute, measuring the displacements of the system. The anchor grout and rock mass were visually inspected to identify any potential failures.

The reaction system (Figure 1) consisted of a 6 m long steel beam, supported on inclined metal supports to take the 49° inclination of the brace anchors.



Figure 1. Reaction system for brace testing – Site 1.

The horizontal forces were taken by anchors in the ground and by pulling two slings towards a bulldozer located behind the device. An Enerpac hydraulic cylinder with a 1,000 kN capacity was used to apply axial loads.

The graduation of the dial test indicators (Figure 2) to measure the displacements was 0.01 mm, mounted on a 5 m long structure, independent of the load application system. The dial test indicators were placed on a plate fixed to the bar, approximately 0.20 m from the head of the anchor.

2.2 Results obtained in brace anchor tests

No failure of the soil surrounding the grout was observed in any test, ruling out the case of pull-out failure. Localized cracking of the cementitious grout was observed on the surface, which did not affect the load transmission capacity of the bar to the grout.

In all cases, the maximum test loads were 556 kN and it was observed that the displacements are significantly similar in both rock and soil for the anchor lengths considered. This confirms that for the adopted anchor lengths the displacements occur due to steel creep rather than due to grout-reinforcement or grout-soil displacement.



Figure 2. Strain measurement system for brace testing – Site 1.

In the inclined anchors in the ground, the maximum displacements varied between 14 mm and 17.5 mm, for anchor lengths of 8.20 m. For the solid bar anchors inclined in rock, the maximum displacements were 11 mm and 14 mm, with the effective lengths being 4.60 m and 5.00 m respectively.

Figure 3 presents the load displacement behavior for three different anchors. One has 8.2 m long in a cohesive soil and the other two are the solid bar cases: one has 4.6 m long in a granite massif rock and the other has 5.0 m long in a sandstone massif rock. The degree of weathering of the rock massifs varies in depth, being classified between highly and moderately weathered, corresponding to grade IV to grade II according to the classification proposed by International Society of Rock Mechanics (ISRM 1981).

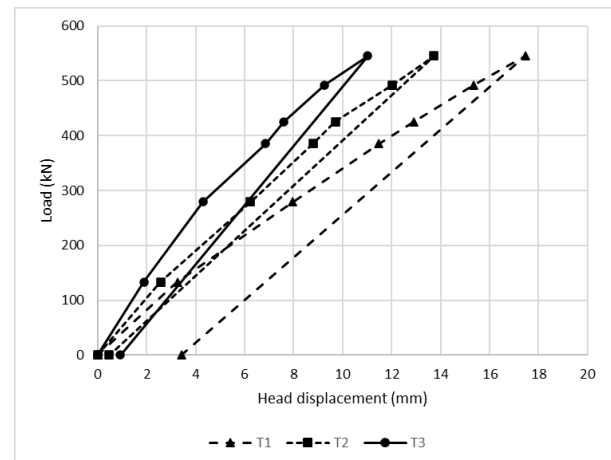


Figure 3. Load-displacement behavior of inclined anchors. T1: 8.2 m long, 40 mm diameter anchor in cohesive soil; T2: 4.6 m long, 29.6 mm diameter bar in granite rock; T3: 5.0 m long, 29.6 mm diameter bar in sandstone.

All anchors have been conservatively designed for the project loads and the resulting displacements were admissible, according to the adopted criteria. Failure occurs due to creep of the anchor bar and not due to bar-grout or grout-rock bond.

The residual displacements are quite small and show that, although the elastic behavior is exceeded, the anchor barely enters the plastic phase of the load-displacement diagram.

There is a margin of resistance, both in terms of bar-grout and grout-rock bond capacity, for the anchor depths and design loads considered, in all the devices tested. If the anchor depths are not modified, the yield stress of the steel of the anchor bars determines the resistant capacity of the system.

2.3 Vertical anchors

For the approval of the vertical anchors, 20 anchors were installed (in locations 26, 30, 219, 242) in 3 types of rock. The anchors had diameters between 25 mm and 32 mm, with anchor lengths between 3.20 m and 5.50 m.

The tests had to reach loads between 270 kN and 500 kN, corresponding to the design load increased 30 %. The testing procedure was similar to that implemented for brace anchors. The reaction system (Figure 4) consisted of a 6 m long steel beam, supported on concrete blocks and a ½" steel plate. The comparators (Figure 5) were mounted on a structure independent of the load application system, 5 m long. The dial test indicators rested on a plate fixed to the bar, approximately 0.20 m from the head of the anchor.



Figure 4. Reaction system for vertical anchor testing – Site 1.

2.4 Results obtained in vertical anchor tests

No failure of the soil surrounding the grout was observed in any test, ruling out the case of pull-out failure. Localized cracking of the cementitious grout was observed on the surface, which does not affect the load transmission capacity of the bar to the grout.

The maximum displacements varied between 2.6 mm and 13.3 mm. Displacement stabilization at constant load (displacement speed less than 0.02 mm per minute) in each loading step was always reached before 5 minutes.

All anchors have been conservatively sized for the design loads and the resulting displacements were admissible according to the adopted criteria. The results obtained for the vertical anchors are alike to those obtained for the brace anchors. Failure occurs due to creep of the anchor bar, and although the reversible elastic behavior is exceeded, the anchor barely enters the nonlinear phase of the load-displacement diagram, and residual displacements are small-scale. In the same way, if the anchorage depths are maintained, the yield strength of the steel in the anchor bars determines the resisting capacity of the system.



Figure 5. Strain measurement system for vertical anchors - Site 1.

3 HIGH VOLTAGE LINE 500 KV MELO – TACUAREMBÓ – SITE 2

On the 500 kV Melo - Tacuarembó High Voltage Line, three homologation tests were conducted on inclined anchors (50°) in the ground for foundations of towers, for UTE.

These were DYWIDAG DW 36 mm type bars, with grout with a characteristic compressive strength (f_{ck}) of 30 MPa or higher. Anchor lengths varied between 10.5 m and 12 m. The soil was composed of sandy clays with a N value between 15 and 30 blows obtained under Standard Penetration Tests (SPT).

The tests had to reach a load of 900 kN, corresponding to the design load increased by 30 %. The test procedure consisted of a first preload cycle (up to 10 % of the test load) to stabilize the system, and then two load and unload cycles until the maximum test force was reached. In each cycle, the loads were increased in steps of 25 %, 50 %, 70 %, 80 %, 90 % and 100 % of the maximum test load, maintaining the load for no less than 10 minutes and taking measurements after 2, 5 and 10 minutes. In the last step, measurements were taken up to 30 minutes.

The reaction system (Figure 6) consisted of a steel beam supported on two concrete blocks of sufficient size and capacity to transmit the load to the ground without considerable displacements. The distance between internal edges of the supports was 3.50 m. The comparators (Figure 7) were mounted on a 4 m long structure independent of the loading system. They rested on a plate attached to the bar, situated about 0.10 m from the head of the anchor.

3.1 Results obtained in inclined anchor tests – Site 2

On the test of the 12 m long anchor in the location 283, the maximum test load (900 kN) was reached in the two load cycles, with maximum displacements of 22.05 mm and 23.47 mm, and remnants of 1.50 mm and 0.25 mm, in the first and second loading cycles respectively. The anchor behaved in a linear elastic manner up to the design load. The failure load is conditioned by the yield stress of the bar, which is defined as 1070 kN for approximately 35 mm of displacement.



Figure 6. Reaction system for inclined anchor testing - Site 2.

On the test of the 10.5 m long anchor of the same location, the maximum test load was not achieved. Having reached a load of 600 kN, the failure of the soil surrounding the grout was observed (Figure 8), noting that the anchor was pulled out of the soil without failure of the steel-grout bond. Localized cracking of the cement slurry at the surface was not observed at any time.



Figure 7. Strain measurement system for inclined anchor testing - Site 2.

Since the maximum test load was not reached (nor the design load) due to the failure of the surrounding soil in the form of a failure cylinder and the results obtained, the anchor design had to be modified.

In the test of the 10.5 m long anchor in the location 54, at 650 kN of the first load cycle, cracking was observed in the head of the anchor, between the soil and grout. Due to the displacement produced, it was decided not to reach 100 % of the maximum load (900 kN), reaching 760 kN, unloading and recording the recovery and remaining displacements. Next, a second loading cycle was conducted up to 760 kN and unloaded. Recovery and remaining displacement were recorded.



Figure 8. Breakage of soil surrounding the grout. Location 283 - Site 2.

Finally, it was decided to proceed to a third loading cycle in order to reach 100 % (900 kN) of the maximum planned load or failure of the anchor. However, the maximum load reached was 840 kN due to the failure of the reaction system (compression supports), see Figure 9. Therefore, the test was interrupted for safety reasons. Figure 10 presents the load-displacement behavior obtained for this test. It is possible to observe some plastic displacements attaining the design load.

At the end of the cycle, it was found that the cracking in the head of the anchor, between the soil and the grout, was stabilized. The failure load was estimated in the order of 850 kN, with an associated displacement of 35 mm.



Figure 9. Failure of the reaction system support - Site 2.

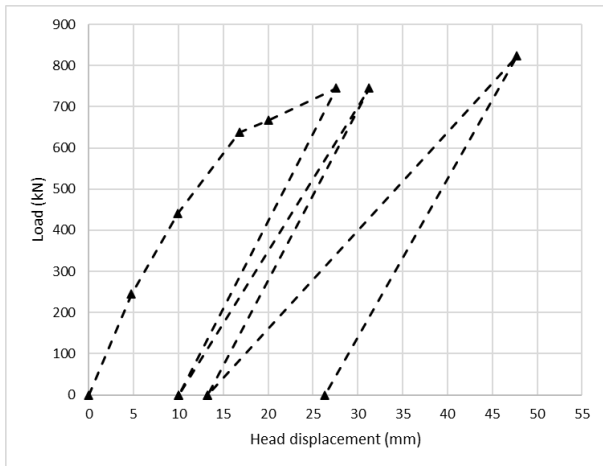


Figure 10. Load-displacement behavior for the test on location 54 – Site 2.

4 TESTS ON HIGH VOLTAGE LINE 500 KV TACUAREMBO – SALTO – SITE 3

On the 500 kV Tacuarembó - Chamberlain, Chamberlain - Salto Grande High Voltage Line, four anchor approval tests were conducted for tower foundations.

These were vertical steel bars anchored 3 m into a basalt massif rock. The tests had to reach a maximum load of 225 kN. The test procedure consisted of a first adjustment load of 30 % of the maximum test load to verify that the entire system was working correctly. Then, a load and unload cycle was carried out, with five load steps at 0 %, 20 %, 40 %, 60 %, 80 % and 100 % of the maximum test load.

In each of the load steps, the load was applied for 5 minutes, and the corresponding reading of the dial test indicators was taken to check the stabilization of the displacements.

To verify that, a specific test device was prepared to test loads of up to 300 kN in tension according to the diagram in Figure 11, which allowed the measurement of displacements with a dial test indicator at the free upper end of the anchor (upper stop) and another dial test indicator on the rock support base.

4.1 Results obtained in anchor tests – Site 3

On the four tests conducted (in the location 92, 518, 561 and 622) it was observed that displacement of the free steel bar, above the anchors, presented a linear elastic behavior, which was in accordance with the theoretical modulus of elasticity for steel.

The anchor tests had a linear behavior with insignificant displacements, varying between 0.33 mm and 1.70 mm for the maximum loads achieved.

It was not possible to apply the criteria to determine the failure load of the anchor using the approximation methods proposed by the IEC1773-96 standard since the yield load was not reached for the maximum load of the tests.

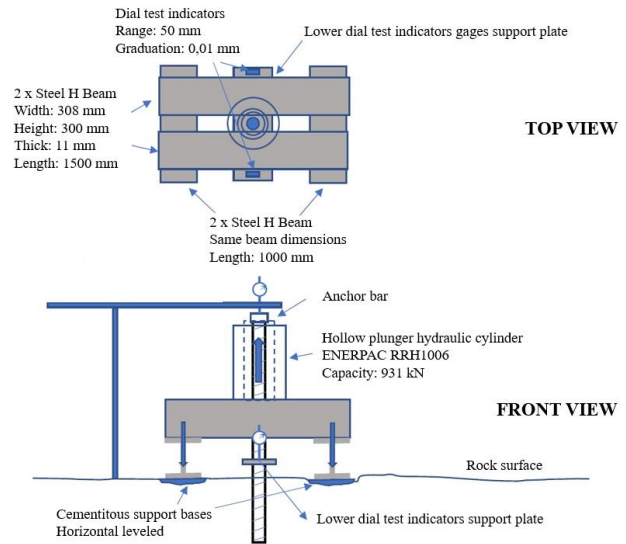


Figure 11. Test device scheme for vertical anchor testing - Site 3.

5 TESTS ON HIGH VOLTAGE LINE 150 KV MINAS – SITE 4

On the 150 kV Minas High Voltage Line, two approval tests were conducted on anchors for tower foundations.

The tests corresponded to a vertical 20 mm diameter steel bars, anchored 2.5 m into the ground. The rock formation is composed of slightly weathered gneiss. The maximum test load to be reached was 130 kN. The second test corresponded to a vertical 25 mm diameter steel bar, anchored 2.0 m in a gneiss rock massif. The maximum test load in this case to be reached was 160 kN.

The test procedure consisted of a first adjustment load of 30 % to 40 % of the maximum test load to verify that the entire system was working correctly. Then two charge and discharge cycles were planned, with five load steps at 0 %, 20 %, 40 %, 60 %, 80 % and 100 % of the maximum test load.

In each of the load steps, the load was left applied for 5 minutes and the corresponding reading of the dial test indicators was taken to check the stabilization of the displacements.

To verify the four possible failure modes, a test device was prepared (see Figure 12) that allowed the measurement of displacements with a dial test indicator at the free upper end of the anchor (anchor head) and another dial test indicator near the rock surface, δ_A and δ_B , respectively.

An Enerpac hydraulic cylinder with a capacity of 1,000 kN and a stroke of 150 mm was employed for loads application. Load measurement was conducted using a manometer gauge with a maximum pressure of 70 MPa.

The graduation of the dial test indicators to measure the displacements was 0.01 mm, with a maximum extension of 50 mm. The dial test indicators used for displacement measurement had a graduation of 0.01 mm, with a maximum range of 50 mm.



Figure 12. Anchor testing device for vertical anchors – Site 4.

5.1 Anchor testing results – Site 4

In anchor test 1, during the maximum load of the initial loading cycle, the free bar steel reached its yield strength limit, resulting in its fracture at one of its ends (refer to Figure 13). The test results are summarized in Table 1. Figure 14 presents the load displacement behavior at the anchor head; it is possible to note the decrement on stiffness before the failure detected in the bar due to yield stress.



Figure 13. Anchor breakage due to steel creep – Site 4.

In anchor test 2, the yield stress of the steel was not reached. Regarding only the displacement near the rock surface (δ_B), both tests had a linear behavior with insignificant displacements, ranging between 0.40 mm and 0.50 mm for the maximum loads reached in each cycle. In both cases the failure load is limited by the yield strength of the steel.

Table 1. Maximum and remanent displacements obtained on anchor tests - Site 4.

	Anchor 1	Anchor 2
Maximum load (kN)	130	160
δ_A – 1 st cycle (mm)	18.63	4.64
δ_B – 1 st cycle (mm)	0.41	0.48
$\delta_{B,remenant}$ – 1 st cycle (mm)	-	0.37
δ_B – 2 nd cycle (mm)	-	0.12
$\delta_{B,remenant}$ – 2 nd cycle (mm)	-	0.01

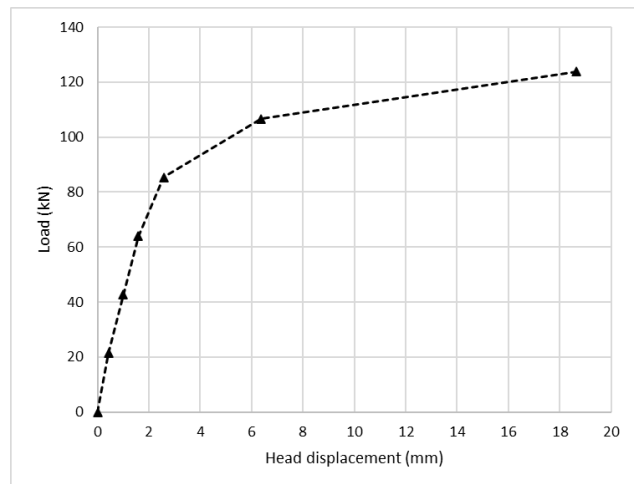


Figure 14. Load-displacement behavior of a bar exhibiting a yield failure - Test 1 - Site 4.

The application of criteria to determine the breaking load of the anchor using the approximation methods proposed by the IEC1773-96 standard was not feasible, as the anchors did not reach their yield load during the maximum load of the tests.

6 CONCLUSIONS

To perform the ground anchor tests for high voltage electrical transmission towers, it was necessary to establish procedures in accordance with the technical specifications mandated by the contractor and relevant regulations. Specific test devices were developed, designing the reaction, loading and displacement measurement systems, depending on the characteristics of the anchor to be evaluated.

The arrangement of the measuring instruments and the visual inspection made it possible to determine the anchor failure mode, for the cases where failure was reached. It was determined that the ultimate load was limited by the yield strength of the steel at all anchors at Sites 1 and 4. Varied failure modes were encountered at Site 2: failure of the steel bar, general failure of the rock mass, and failure of the rock-grout bond. At Site 3, although the maximum

test loads were reached, it was not possible to establish the failure mode.

Beyond the validation of the design of the anchors and the role in quality control, the tests allowed the optimization of the foundation design in some of the tower foundation works. Future studies could focus on the long-term performance and monitoring of ground anchors under various load conditions.

7 ACKNOWLEDGEMENTS

The authors express gratitude to the national energy company UTE, as well as the construction companies Techint, Saceem, CEMEC, and Teyma.

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The paper was published in the proceedings of the 17th Pan-American Conference on Soil Mechanics and Geotechnical Engineering (XVII PCSMGE) and was edited by Gonzalo Montalva, Daniel Pollak, Claudio Roman and Luis Valenzuela. The conference was held from November 12th to November 16th 2024 in Chile.