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MECHANICAL EVALUATION OF THE WELDED UNION OF A TIE-RODS FOR USE IN SLOPE CONTAINMENT

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Abstract. *The anchored wall is a slope containment method in which metal tie-rods are introduced into the ground in drilled holes through a reinforced concrete wall. These tie-rods in most cases require a joint, since they need to reach great depths, which is usually made by bolts. In this work a mechanical evaluation of the joint of tie-rods made by welding, instead of bolts, used in the application of slope containment with anchored wall, will be evaluated using the maximum tensions supported by these joints and thus their viability. Tensile, bending and penetrating liquid tests were performed on samples of CA-50 rebar, specified by GERDAU©, which allowed a quantitative and qualitative analysis of joints welded by shielded metal arc welding process (SMAW) and gas metal arc welding (GMAW) by metal inert gas (MIG) process.. These rebar are able to withstand high tensile loads due to the medium carbon concentration and the high alloy contents, ideal for use in slopes containment, which are used by VIABRAS company to contain a dam in Santa Teresa-ES. Based on the tests, it was observed that the SMAW and MIG welds in the tie-rods support, on average, a load of 15.7 and 16.28 tons, respectively. The results have indicated that the addition of heat by the welding process generates a thermally affected zone that contributes to increase the resistance of the tie-rods, generating underestimation of the calculated loads. The basic parameters were the first points of indication of the welded joints of the specimens, points obtained by the tensile test. The load required in design by VIABRAS company for the use of these tie-rods was 14 tons strength (overestimated load) the traction. The feasibility of the use of welded joints for the works of this type of application, according to the requirement of the mechanical property analyzed, allowing the use of the same to instead of bolted joints which can lead to project savings.*

Keywords: *rebar, anchored wall, SMAW, MIG, tensile test.*

1. INTRODUCTION

According to Dutra (2013), slope instability is a problem that is very much experienced in Brazil, due to the disordered human occupation of these sites. This problem can cause serious accidents and put people's security at risk. "Rainy seasons with high rainfall have become real torments for the population, in those periods when the slopes are more susceptible to landslides, due to the increase in excess pore pressure that reduces soil resistance to shear." As a result, slope containment buildings have become important in the current scenario, which makes it important to study new technologies and improve processes.

The anchored wall is a slope containment method in which tie-rods (metal bars) are introduced into to the ground in drilled holes through a reinforced concrete wall. Cement paste is then injected at high pressure into the bore to promote the bolting of the bars, which, after curing the cream, will be pre-attached to the concrete wall causing the entire structure to be "pushed" against the slope (Dyminski, 2007).

According to the work carried out by Fiamoncini (2009) "The anchored walls had a great development in Brazil thanks to the tireless work of Professor A. J. da Costa Nunes of the Federal University of Rio de Janeiro, who developed the Brazilian method of bolting (1957) in the company Tecnosolo S. A.".

Being one of the main components of the anchored wall, the tie-rods are responsable to make a connection between the bulb anchored in the ground and the containment panel on the outside of the slope. The tie-rod steel is installed on the soil in a sheath that protects against a humidity (Watanabe and Peão, 2017).

In the 1960s, it was common to use restrained rods with loads of around 200 kN with a spaced of 3 m in reinforced concrete slabs up to 20 cm thick. Over time, the technology has improved these items, with a tendency to increase the spacing between rods, and consequently increase of its load, even with the increase of the thickness and resistance of the support structures. Another advantage is the constructive simplicity, in addition to that it is self-supporting, that is, it is always possible to construct rods in such a way that the reinforced structure does not require complex foundation details (Joppert Jr, 2007).

Tie-rods are linear elements capable of transmitting tensile forces between their ends. In the geotechnical applications of rods, the end that lies outside the ground is the anchor head and the end that is buried is known as the anchored portion and is called the anchoring length or bulb (Lb). The section connecting the head to the bulb is known as free or free length (Ll) (Joppert Jr, 2007). Lengths are shown in Fig. 1.

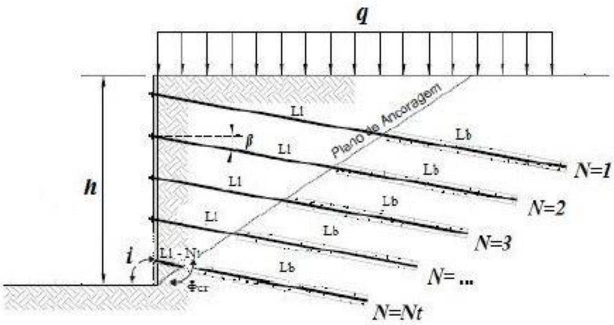

Figure 1. Schematic of an anchored wall.

Source: Piccinini, 2015.

The tie-rods used in this case study are composed of two GERDAU© GG 50 rebars joined by welding. Considering the high loads in which these components will be subjected, it is evident the importance of the welding processes, which preserves the integrity of the work (Comercial GERDAU©, 2017)

The tests were performed with the objective to evaluate the quality of the welds that will join the metal bars that make up the tie-rods used in this case study. For this purpose, tensile, bending and penetrating liquid tests were carried out in samples and different types of welds were evaluated in order to evaluate the maximum stresses supported by the welded joints (quantitative analysis) and their behavior in relation to appearance of cracks and other characteristic defects.

Figure 2 shows the technical design of the tie-rod on the slope. In the VIABRAS project, it was specified which accessories should receive anti-corrosion protection with epoxy-based paint.

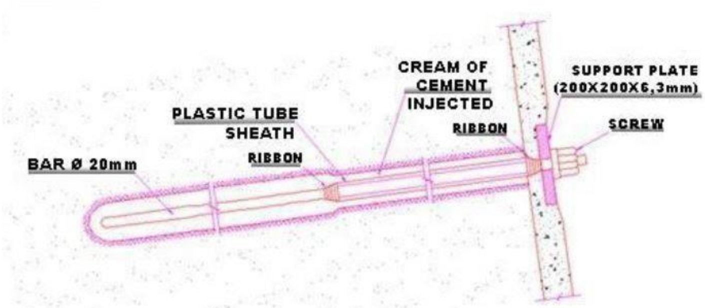

Figure 2. Schematic view of the tie-rod installed on the slope

The execution of the bolting in a curtain for a containment of a slope is done following a few steps: drilling of the solid mass, assembly and installation of the tie-rods (Fig. 3), injection of cement slurry at the inner end of the bore to surround the rod and protension. The drilling of the massif is done by machines called drills, following depth, angle and diameter determined in design. Among the factors that determine the depth of the drilling is the need to find a sturdy area for the anchorage of the tie rod. The rods are assembled according to the design specification and after their introduction, the injection of cement by gravity is done by means of a PVC pipe. After full curing of the cement, the protrusion can be made using hydraulic jacks and are placed on the parts making up the "head" of the tie-rod – the grade wedge, the bearing plate and the fixing nuts or claws. After the bolting of the massif, the reinforced concrete curtain is executed, which will actually contain the slope (Corsini, 2017).

Figure 3. Introduction of tie rod.

Figure 4 shows the chainlink mesh ready for protension stage of the work carried out by VIABRAS on the slope in Santa Teresa.

Figure 4. Struts with rods and crossbar screens.

The anchored wall requires periodic inspection for evaluation of the concrete and tie-rod heads. Over time, in sandy and clayey soils, the presence of water may require pretensioning (retensioning) adjustments in the tie rods and recomposition of cement layers (reinjection) that protect steel cables (Watanabe and Peão, 2017).

2. THEORETICAL REFERENCE

The tensile test consists of the application of increasing uniaxial tensile load on a specific specimen until rupture (Dalcin, 2007).

This test is often used in the industrial area due to the advantages of providing quantitative data of the mechanical characteristics of the materials, which allow to evaluate the feasibility of a more precise study of the possibilities of using the materials analyzed. Through the tensile test some parameters can be found, such as modulus of elasticity, yield limit, tensile strength limit and rupture limit. According to Callister (2008) the engineering stress can be calculated by Eq. (1).

$$\sigma = \frac{F}{A_0} \tag{1}$$

Where, σ is the engineering stress, F is the applied instantaneous load and A_0 is the original cross-sectional area before any load is applied.

However, the joints of the tie-rods are subjected to shearing, so according to Hibbeler (2010), Eq. (1) is rewritten in the form of Eq. (2), where τ is the mean shear stress.

$$\tau = \frac{F}{A_0} \tag{2}$$

The specimens can be obtained by machining a sample of the product or can be directly forged or cast, when analyzing the conditions of the material. The cross section can be square, rectangular, hexagonal, circular, annular or any other shape, provided it respects the condition of proportional evidence (Garcia, *et al.*, 2012).

The bending test uses ductile materials, which when subjected to bend, are capable of absorbing large deformations, occurring a certain bending of the specimen, thus not providing quantitative but qualitative results. According to Souza (1982), "the bending process has two variants, called free bending and guided bending", with free bending being the most used to evaluate the quality of the weld.

The penetrating liquid test is applied in order to check for undetectable surface cracks by simple naked eye inspection. In this type of test the cracks and superficial cracks in the part are penetrated by a liquid through the phenomenon of capillarity (Garcia, *et al*, 2012).

In the SMAW welding process the coalescence between the metals is produced by heating them by an electric arc that is established between the coated metal electrode and the piece to be welded. Also called manual welding, this process can be used in a range of materials, such as carbon steels, low-, medium- and high-alloy steels, stainless steels, aluminum, copper and others (Marques, *et al.*, 2011).

The MIG (metal inert gas) and MAG (metal active gas) welding processes use as a heat source an electric arc maintained between the continuously fed nonsupportable electrode and the part to be welded. The MIG process is suitable for the welding of carbon steels, low, medium and high alloy steels, stainless steels, aluminum, magnesium, copper and alloys (Wainer, *et al.*, 1992).

The region of the base metal having its structure changes and/or its properties changed by the welding heat is called the Thermally Affected Zone (TAZ). The characteristics of the TAZ depend fundamentally on the type of base metal and the process and welding procedure (Marques, *et al.*, 2011).

According to NBR 5629 (ABNT, 2006) "The steel section of the debtors should be calculated from the maximum duration of the submitted, having as allowable tension", in the case of permanent tie rods, use Eq. (3):

$$\sigma_{adm} = \frac{f_{yk}\, 0.9}{1.75} \tag{3}$$

Where, σ_{adm} is the allowable stress and f_{yk} is the characteristic tensile strength of the steel.

According to NBR 7480 (ABNT, 2007) "products of nominal diameter 6.3 mm or higher, obtained exclusively by hot rolling without subsequent mechanical deformation process, are to be classified as bars. According to the characteristic value of the flow resistance, the steel bars are classified in categories CA-25 and CA-50 ".

According Gerdau Commercial, Gerdau GG 50 Rebar is supplied in the category CA-50 with ribbed surface, and follow the specifications of normal NBR 7480. Table 1 presents some minimum properties of the bar when subjected to tensile stresses.

Table 1. Minimum properties specifications obtained by tensile test on rebar CA-50 steel Gerdau.

Source: Commercial Gerdau, 2017.

Nominal Diameter (mm)	Nominal Mass (kg/m)	Traction Test (minimum values)			
		Linear Mass Tolerance (%)	Resistance Characteristic of Flow (MPa)	Resistance limit (f_{yk}) (MPa)	Stretching in 10 Ø
20.0	2.466	± 5	500	540	8%

Protension is defined as a process in which tensile stresses are applied on a structural element, in this case, metal bars or wires. Normally, this technique is used in prestressed concrete structures (beams and slabs), tractioning the reinforcement (before or after the concreting of the pieces), so that it ends up inducing a previous state of tensions in the concrete that ends up contributing to the increase of the structural part as a whole. In anchored wall containment structures, the protension technique can be applied to the tie-rods, generating a state of tensions in the system, since the tensioned tie-rods apply a force in the containment structure (face) against the solid one. The main purpose, in this case, is to reduce the displacements of the concrete structure, which must withstand the efforts generated by the tendency of soil mass displacement (Piccinini, 2015).

Generally, the anchored wall structure will be subjected to the buoyancy of the earth (active thrust) resulting from forces applied in its surroundings: soil weight + soil water column weight + permanent loads (such as neighboring buildings or foundations) + accidental loads (in case there is some passageway at the top of the slope or garage etc...) (Piccinini, 2015).

The maximum load stipulated by VIABRAS was 14 tons.

3. MATERIALS AND METHODS

The present work was carried out in the Materials Test Laboratory of the Federal Institute of Espírito Santo. The materials used were: Time group universal testing machine, welded specimens, weldless CA-50 steel specimens, welded CA-50 rebar samples, penetrating liquid, developer, hammer and steel brush. The measurements of the specimens were performed by a pachymeter with an accuracy of 0.05 mm.

The specimens were prepared with two circular section rods welded to a bar that tangents the outer surface of the rods as in Fig. 5, the components being made of the rebar CA-50 steel. Four specimens welded by SMAW process and two welded by MIG process, the specimens were supplied by the company.

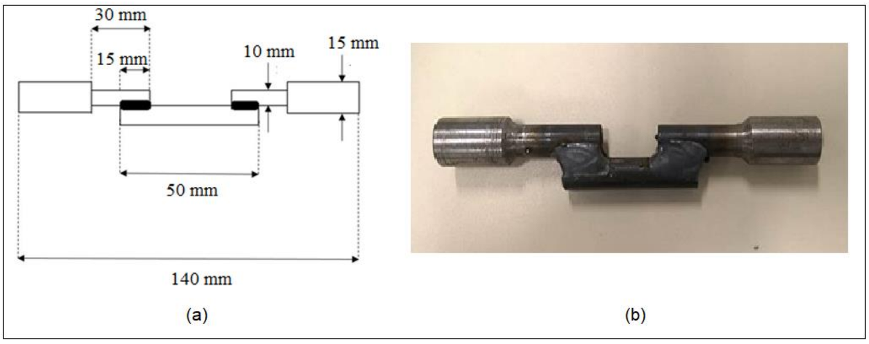

Figure 5. (a) Design of welded specimens, (b) welded specimens.

Due to the nature of the welding process there was variations in length (L) which according to the design shown in Figure 5 is 15 mm and depth (H) of the weld bead. The specimens welded by SMAW process followed the specifications Ø = 2.5 mm E-7018, two passes of each root and fill side, with 100 A. The specimens welded by MIG process, Ø = 1.0 mm wire, one pass from each side to 110 A. They were used in the tensile test and the results were used to estimate the resistance of the actual weld joint, with the speed of the test used being 2 mm / min (Fig. 6).

Figure 6. Traction test being performed on welded specimens.

A traction test was performed on four specimens supplied by the company and removed from CA-50 rebar (Fig. 7a).

The dimensions of the specimens were specified according to Garcia et al. (2012, p. 68) with dimensions in Fig. 7 b. The objective of this study was to determine the limit of flow of the steel, which was taken from a rebar used by VIABRAS in the slope containment located at Santa Teresa.

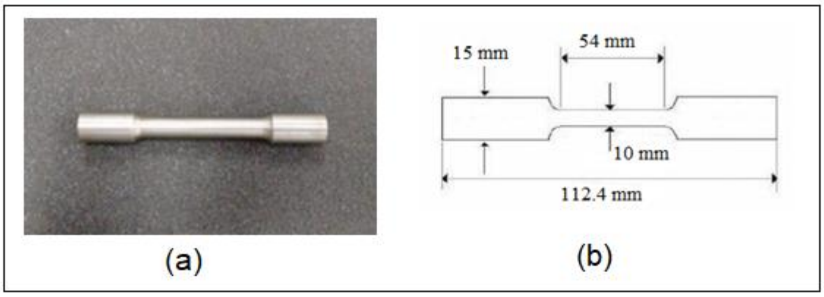

Figure 7. (a) Specimens without welding, (b) dimensions of specimens.

For the bending test, tie-rods welded by SMAW process (Ø = 2,5 mm 7018-1) with 100 A and one pass. At the beginning of this test the distance of 20 cm supports of the universal test machine was adjusted and the cleaver approached in relation to the body to be tested, the speed of 5 mm / min was used for the test, the bending test was type 3 points and as samples bent at 90 ° (Fig. 8).

Figure 8. Sample of welded rebar in the bending test.

Subsequently the pieces were then taken to a cleaning process to remove slag from the welding process, where hand brushes were used. Metal-check fluorescent penetrant was then applied. A after the drying time, a cleaning was carried out, followed by application of developer and finally the black light to reveal the discontinuities.

4. RESULTS AND DISCUSSIONS

It has as a project requirement that the tie-rod support about 14 tons of force (137.29 kN). This is the extreme condition of tensile project in the tie-rod (already taking into account safety coefficients). Equalizing the Eqs. (1) and (3) and substituting the values given in Tab. 1, a permissible force of 87.25 kN is obtained, which indicates that the sizing of the bar diameter for the design is not in accordance with to NBR 7480 (ABNT, 2007). However, in the protension of the tie-rods, where traction of the same occurs with the hydraulic jack, an increase of resistance occurs according to Piccinini (2015) and consequently will generate increase in this admissible force. The tensile stresses must be evaluated in order to reach the specification of the standard.

The test specimens of the solderless CA-50 steel were analyzed by the tensile test to verify the yield limit provided by Tab. 1. Table 2 represents the results generated in the test.

Table 2. Results of tensile tests on weldless test specimens.

Specimens	Yield Strength (MPa)
1	2156.1
2	305
3	393.5

leakage voltage well above expected is observed on test body 1, which can be attributed to the possible quenched of the steel due to the heat coming from the welding process, which indicates that the specimen was removed from a Thermally Affected Zone (TAZ). For the voltage value in this case, the rebar supports a load of 677.36 kN without draining.

The specimens 2 and 3 had a voltage below 500MPa, so considering the lower voltage (305 MPa) the rebar can withstand a load of 95.81 kN below that required in the project. However, taking into account the specified drainage tension of Tab. 1, the rebar supports a load of 157.08 kN, it will withstand the maximum load required without reaching the outlet.

For the welded specimens, the test machine generated strain-force graphs for each of the six specimens. With these graphs the forces of flow were estimated that was analyzed by the first point where the curve of the graph is no longer linear and with this force allied the measurements of the dimensions of the weld, by Eq. (2) was estimated the flow voltage of the welded joint of the tie rod. All of these test bodies were tensile tests and ruptured at the weld joint as observed in Fig. 9. The L and H parameters used for the smaller joint are used to calculate the cross-sectional area ($A_0 = LH$). Table 3 shows the results of tensile tests on welded joints.

Figure 9. Test piece welded after the tensile test.

Table 3. Results of the tensile tests on the bodies of welded tests

Specimens	Thickness of welded (H) (mm)	Length of welded (L) (mm)	Welding Process	Tension (MPa)	Force (kN)	Force (ton)
1	9.00	17.00	SMAW	32.68	5.00	0.51
2	8.50	19.50	SMAW	20.81	3.45	0.35
3	9.00	15.00	SMAW	23.85	3.22	0.33
4	10.00	15.00	SMAW	23.33	3.5	0.36
5	10.00	15.00	MIG	26.00	3.90	0.4
6	8.00	14.00	MIG	26.16	2.93	0.3

A mean flow voltage value for the specimens with SMAW and MIG welding of 25.17 and 26.08 MPa and a standard deviation of 5.18 and 0.11 MPa, respectively, is observed. Thus, based on these flow stresses, we can estimate the maximum force supported on the tensile joints without they flowing. Since the weld dimensions at the joints of the rods are 18 mm thick and 340 mm long and based on Eq. (2), it was possible to estimate the flow strength at the real joints, results presented in Tab. 4.

Table 4. Forces supported by joints.

Type of join	Force of yield (kN)	Force of yield (ton)
Welded by coated electrode process	154.04	15.7
Soldered by MIG process	159.61	16.28

Due to the small dimensions of the bodies of evidence and the small mass of the same, the cooling process in this case is preferably convection, in this case (test specimens) a lower TAZ is obtained. In the case of real rebar, because they have much larger dimensions and mass, the process of heat transfer also occurs by conduction, which generates a larger TAZ and quenched, thus causing a sudden increase of resistance, as shown in Tab. 2. The quality of the welds of these specimens was not verified by non-destructive tests; however, some discontinuities could be perceived by the naked eye in the same as presence of bites, lack of penetration impairing the complete junction of the base metal and some pores. A better quality weld can exhibit much greater resistance to shear. Thus, it is expected that the actual load values will be much higher than the ones estimated, due to the higher TAZ and higher penetration of the actual weld, therefore, the values presented in Tab. 4 were underestimated.

Thus, for the extreme condition stipulated by VIABRAS in the containment of the dam in Santa Teresa (14 tons force) the rods with joints welded by the two processes studied will resist the applied stresses. With respect to the bending test carried out on two rebar samples with SMAW joint, during the test it was possible to observe small fragments (slag due to the welding process) falling during the process. Subsequently after the test, the part underwent a cleaning process, application of a fluorescent penetrating liquid, of a developer substance (Fig. 10) and after verification by means of a black light in a dark environment (Fig. 11), no fractures were observed resulting in a positive qualitative analysis that contributed to reinforce how well the rod will respond to the project. Ensuring that tie rods can withstand possible bending efforts without compromising the quality of their joints.

Figure 10. Sample during drying, penetrating liquid (vial with green detail), developer (vial with red detail).

Figure 11: Sample being inspected.

5. CONCLUSION

It should be noted that the tie-rods are fundamental components for the integrity of the containment work of sloped curtains. In the case analyzed here, the rods are manufactured by the welding of two steel rebar by the MIG / SMAW welding processes. The purpose of this work was to analyze and compare the quality of the welds using mechanical tensile and bending tests, together with a penetrating liquid test to identify cracks and cracks in welded joints.

The test results showed that the welded joints met the requirements of the project satisfactorily, having withstood stresses above the minimum required. The folding test in conjunction with that of penetrating liquid also indicated a good quality of the solder, which did not show cracks or significant cracks.

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