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Instrumented pull test results in grouted split sets, and its comparison with non-grouted test results in an underground manganese mine – Corumbá/MS - Brazil

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ABSTRACT: Rock mass friction stabilizers, commonly called Split Sets, were introduced in the metal mines of the United States and Canada in the early 70s. Split Sets can provide support due to friction between the anchor and the rock surface of the boreholes. As Split Sets are inserted in boreholes with slightly smaller diameter than the diameter of the retainers, the radial force is generated by the compression of the anchor by the drill wall, ensuring its efficiency by friction in this contact interface. In order to increase the maximum load capacity of Split Sets, some mining companies opt for grout injection after the installation of the anchors. The present study presents the results of instrumented pull tests performed in Grouted Split Sets and its comparison with the result of tests performed in Split Sets without the application of cement, in an underground manganese mine. A total of 72 tests were performed in 3 different mine locations, with distinct roof geological characteristics, and the results showed an increase of up to four times the initial strength without the application of grout, considering the best scenario.

1. INTRODUCTION

Split Sets can provide pressure support due to friction between the anchor and the rock surface of the holes. These were the first types of friction anchors to be used and still are the most widely type operated in underground mining. Split Sets consist of steel tubes sectioned longitudinally, and a steel ring fixed at its lower end, able to apply force to a steel plate that transfers the load to the surface of the excavation. As the Split Sets are inserted in boreholes with slightly smaller diameter than the diameter of the retainers, the radial force is generated by the compression of the tube over the drill wall, ensuring its efficiency by friction in this contact interface (Komurlu and Demir, 2019).

According to Komurlu and Demir (2019) the length of the Anchor is an important parameter for load capacities of support with Split Sets. Load capacity increases with bigger length of anchor. In addition to the length of the Split Set, other parameters have a great influence on the efficiency of this type of anchoring. A factor of great impact on the maximum load supported by the Split Set is the drilling diameter. When anchor of the same characteristics and dimensions are used in different diameters of perforation, we realize that there is a tendency to obtain higher maximum loads using smaller diameters, as shown in figure 1 (Tompson et al. 1999).

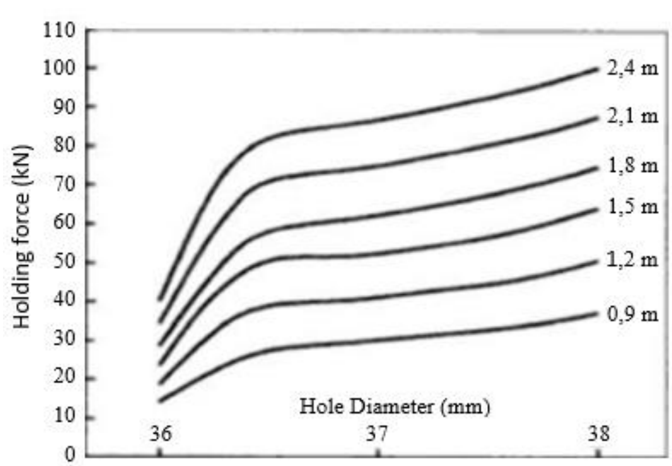

Fig. 1. Increased load capacity, with progressive decrease in the perforation diameter, for different anchor lengths (Tompson et al. 1999).

Some authors, such as Hoek et al. (1995), Tomory (1997), Stillborg (1994), Tompson et al. (1999) recommend the use of drilling diameters from 1 to 4 mm smaller than the nominal diameter of the anchor used.

What we can observe from actual bibliographies is that the loads obtained in Split Set pullout tests show great variability. Several parameters can influence the dispersion of the results, giving a normal distribution of the data. Among these parameters the most important ones are: the characteristics of the rock mass, the contact area of the Split Set with the rock, the drilling diameter, the features and properties of the anchor steel, the quality of the installation. Some of these factors, such as rock type, drill bit size and time needed to install the split set are easily obtained. Others, such as contact area and installation quality, are very difficult to determine or not readily quantifiable. (Tomory, 1997).

Pullout tests are usual experiments to determine the load capacity of this type of anchorage. The purpose of this test is to evaluate the load capacity of Split Sets under axial load conditions. The maximum load supported by the contact/adhesion between the rock mass and the steel surface is generally reached shortly before Split Set starts sliding. After reaching the maximum value of load capacity, the Split Set can be removed by sliding it in the hole under application of a load slightly lower than the peak values (Komurlu and Demir, 2019).

In order to get higher maximum adhesion load using the friction anchors of the Split Set type, some mining companies choose to inject cement after installing the anchors. This method allows a greater load transfer between the Split Set and the excavation surface. Villaescusa and Wright (1997) carried out tests on grouted and non-grouted Split Sets in Australian mines and the results ranged from 10 tons/m to 15 tons/m, with pullout tests performed at 5.5 and 7 hours after grouting. According to the authors, the injection of cement can increase the maximum bond load value up to four times using grouted Split Sets, meaning the values depend on the sum of the driving/mechanical contact of the split set with the rock, added to the resistance of the grout in contact with the rock along the divided axis of the Split Set. It is also mentioned that the high compressive strength of the grout can hinder the inverse deformation (retraction) of the steel, which makes the Split set difficult to slide. The results obtained are also corroborated by tests carried out by other authors (Fuller and Dugan, 1992, Thompson and Finn, 2018).

The use of expansive cement additives can increase the diameter of the anchor within the hole, which can also increase the maximum load required for anchor pullout. Davison and Fuller (2013) carried out experiments with the insertion of special mortars, with high expansive capacity, in very bad quality rocks (soft clays), and the results were satisfactory.

2. OBJECTIVES

The objective was to analyze the increment of resistance generated by the injection of cement inside the Split Sets, which were installed in unfavorable rock conditions for drilling inside an underground manganese mine located in the municipality of Corumbá - MS, Brazil.

3. METHODOLOGY

To fulfill the field pullout tests, a pump set (Enerpac P392) and hydraulic jack (Enerpac RCH302) were used. In tests with Split sets a steel bar is inserted to guarantee its extension thus allowing the load to be transmitted. This is also known as a traction rod, made of a threaded steel bar, which is attached to the Split Set ring. A loading hydraulic jack is mounted and exerts pressure against the rock in order to pull out the Split Set already installed. To ensure that the load applied is as axially as possible, a support table is used with three-point adjustments. Figure 2 shows the setup.

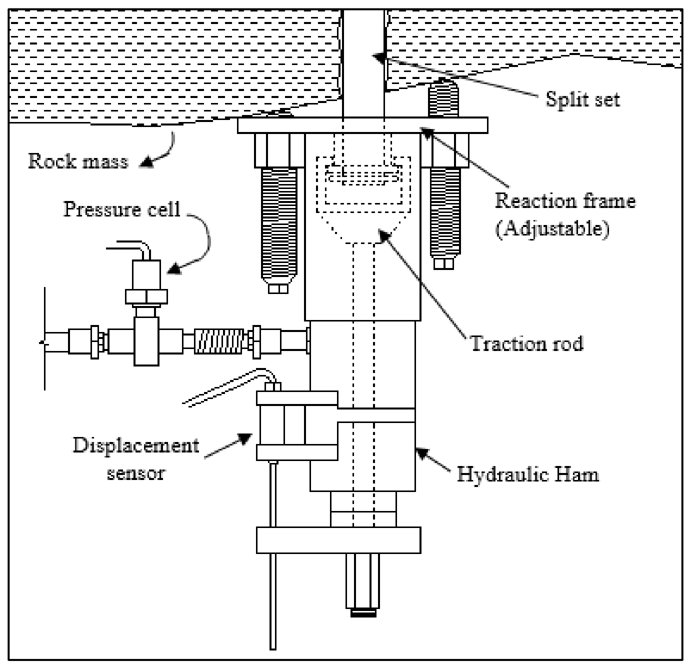

Fig. 2. Instrumented pullout test setup.

The tests were performed to get a better understanding of the loading and displacement obtained during the experiment, and to determine with accuracy the maximum load supported. A device set from YieldPoint®, called PullTest Unit (PTU), was used. This set consists of a displacement sensor, an in-line pressure sensor, a data acquisition system and a specific software.

The displacement sensor uses the principle of magnetostriction to measure the relative position of a flexible waveguide and a ring magnet. An in-line pressure cell is used for charging. The load applied to the Anchor System can be calculated based on the test system line pressure multiplied by the area specified for the hydraulic jack used. These two transducers are connected to a unit which receives the data and sends it in real time via Bluetooth to the software, this way generating instantly displacement x load graphics throughout the pull-out test, on a tablet or Smartphone.

The pullout tests were carried out in three different locations in the mine, and their differences about geotechnical domains, lithology and/or degree of fracturing. Split Sets with a length of 2.20 m, a nominal diameter of 42 mm and a steel thickness of 2.65 mm in drillholes with a nominal diameter of 38 mm were installed, according to historical conditions used in the unit. A total of 72 samples for pullout test were prepared, 36 of them with injection of cement in its interior, with the purpose of a better understanding of the adhesion resistance of the Split Sets in internal filling condition, and at the rock-steel interface of reinforcing element.

To inject cement grout, a mixer and an injection pump were used by descending method. This way the cement initially fills the bottom of the hole while the hose is slowly retracted, filling up the entire column of the Split Set. The water/cement ratio used for this method was 0.4 to obtain a more fluid paste, thus allowing percolation through the empty spaces.

Besides to cement and water the expanding additive Intraplast® N, from the manufacturer Silka®, was used. Its main function is to expand the cement grout in the process, making its volume to increase from 3 to 10%.

3.1 Visual investigation by filming.

Prior to fulfill the pullout tests, the drills for the installation of Split Sets in the excavation ceilings have been filmed, as well as the inside of the anchor that had already been installed. Due to mass characteristics of the mine where this study was carried out, the main objective was to observe the existence of integrity loss on the sides of the boreholes, caused by the deterioration of its rock mass during rotopercursive drilling, according to its real quality.

4. RESULTS AND DISCUSSIONS

In the first location, confirmed by recording, some points of irregularity on the wall of the holes were observed, with millimetric fractures (figure 3, A and B). In the second location, with a different lithology, it is possible to see that the drilling walls are intact and homogeneous (figure 3, C and D). Finally, in the third location, despite the same lithology as the first one, an increase in the number and size of fractures is visible, which is a significant outcome regarding the quality of the drilling (figure 3, E and F).

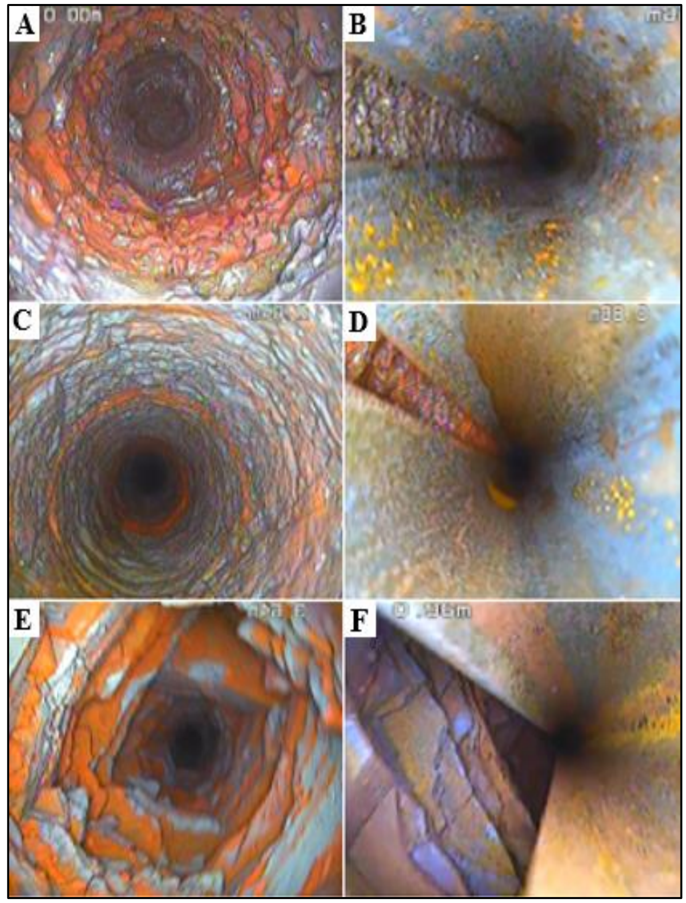

Fig. 3. Drilling condition in location 01 and contact between the rod and the hole wall for this condition. (B and C): Drilling condition in location 02 and contact between the rod and the hole wall for this condition. (D and E) Drilling condition in location 03 and contact between the rod and the hole wall for this condition.

We can see that the structures and degree of fracturing of the rock indicates unfavorable conditions for the application of the Split Set, causing enlargement of the holes, compared to their nominal drilling diameter, and decreasing the contact at the Split Set/borehole wall interface. As previously presented, the diameter of the hole is a critical factor in the application of Split Sets and can greatly reduce the adhesion strength of the containment.

In location 03, especially, we can see that the condition of the hole wall significantly influences the contact area between the Split Set and the rock mass, leaving empty spaces in this interface. Therefore, the cement injection is used to fill up these empty spaces and, consequently, increase the friction surface of the reinforcement element with the rock, thus increasing the adhesion resistance.

Figure 4 graphically presents the average load per metric length obtained for bond strength with the application of cement in the Split Sets for each location of the mine, in comparison with the values obtained without cementation.

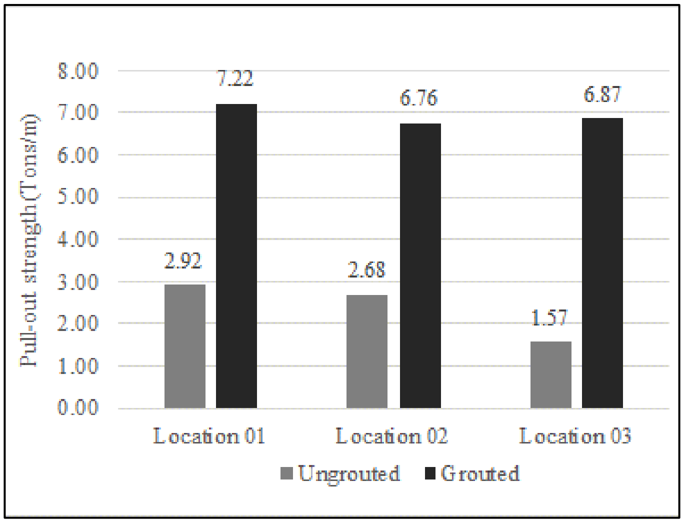

Fig. 4. Average loads per metric length, obtained for the bond strength with the application of cement in comparison with the values obtained without the practice of grouting.

The results show: for installation using the conventional way, in drilling conditions according to the films, the maximum load per metric length is greatly influenced, with relatively low values. Those found for the averages of the tests performed in Split Sets without cement injection were 2.92, 2.68 and 1.57 for locations 01, 02 and 03, respectively.

As for grouted Split Sets, there is a significant increase in maximum loads and more homogeneous results among the three analyzed locations, regardless of the drilling conditions in each of them. The values found for the averages of the tests carried out in grouted Split Sets were 7.22, 6.76 and 6.87 for locations 04, 05 and 06, respectively.

Table 1 presents the average values of the tests for each location, as well as the increments in the maximum adhesion load after the grout injection:

Table 1. Mean values of maximum bond load for each location and resistance increments after grout application.

Section	Methods	Averages Ton	Averages Ton/m	Standard deviation	Resistance increase
Location 01	Ungrouted	6.41	2.92	0.70	248%
	Grouted	15.89	7.22	0.67	
Location 02	Ungrouted	5.90	2.68	0.56	252%
	Grouted	14.86	6.76	0.57	
Location 03	Ungrouted	3.46	1.57	0.36	437%
	Grouted	15.12	6.87	0.71	

These resistance increments are linked to the filling of empty spaces left by drilling imperfections, thus increasing the friction surface, as well as the filling and internal expansion of the anchor, which prevents reverse deformation and increases the radial force exerted on the drillhole wall.

Due to this significant increase in adhesion resistance, the values obtained in consequence have influenced the maximum load supported. During the pullout tests, deformations were observed in the Split Set ring (Figure 5, B) and ruptures of the containment element's steel (Figure 5, A) before the Split Set slipped through the hole.

Fig. 5. (A) Total rupture of split set steel. (B) Ring deformation and beginning of weld breakage.

These ruptures happen abruptly, as it can be seen in the graphs generated by the software (Figure 6). We can also see the differences between the maximum loads supported in grouted and non-grouted Split Sets testes, and the characteristics of the displacement vs. load.

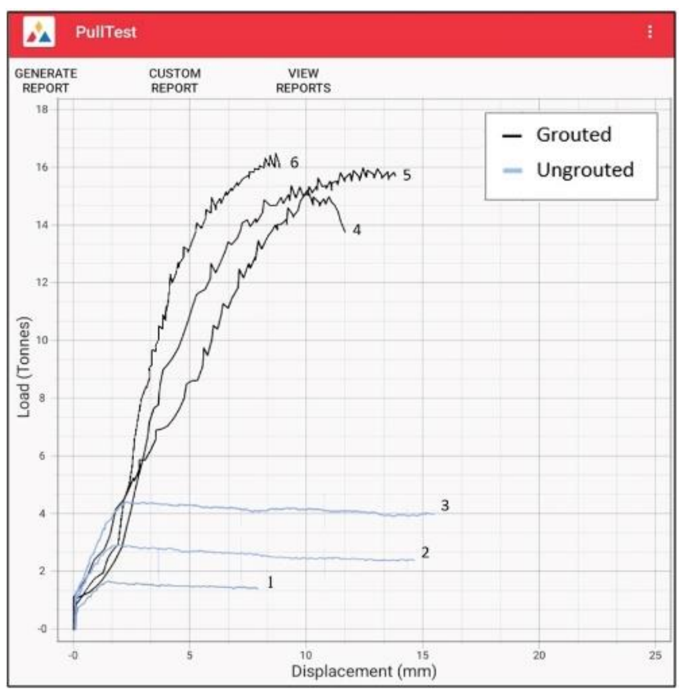

Fig. 6. Displacement (mm) x load (Ton) graphs obtained by Yield Point® Pull Test software. Tests performed on ungrouted Split Sets (1, 2 and 3). Tests carried out in grouted Split Set (5 and 6). Tests carried out in grouted Split Sets where there was rupture of the anchor steel (4).

5. CONCLUSIONS

The application of cement in Split Sets can, significantly, increase the anchorage strength, reaching values ranging from approximately 2.4 to more than 4 times the initial strength, considering the best scenario. Therefore, this method can be used to overcome situations in which the maximum load reached is low, due to some factors. For example, in situations where the quality of drilling leads to a loss of efficiency, for all drills or part of them. In these cases, cement injection may be an economically viable option to recover existing installations without the need for new drilling and installations to recompose the containment mesh, or even as an operationally adopted practice.

The gain in resistance provided by the injection of cement raises maximum load values in such a way that the maximum load does not depend only on friction, but also on the steel resistance as well as the ring welding. Accordingly, it can be said that the maximum efficiency of this type of containment is reached, because the maximum load is now controlled by the Split Set steel resistance combined with ring welding resistance.

However, must also be considered that one of the main characteristics of the Split Set, which accepts large deformations of the rock mass, can be reduced by a possible increase in the rigidity of the system when cemented.

Equally noteworthy is the precision and reliability that the instrumentation offers. It is also possible take conclusions according to the graphics generated by the software.

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