Detailing the use and installation of the Time Domain Reflectometer in geomechanics monitoring

Arthur Resende Matos
MecRoc Engenharia, Belo Horizonte - MG, Brazil, arthur.matos@mecroc.com.br

Alexandre Assunção Gontijo
MecRoc Engenharia, Belo Horizonte - MG, Brazil, alexandre.gontijo@mecroc.com.br

Leandro Roque Fonseca
MecRoc Engenharia, Belo Horizonte – MG, Brazil, leandro.fonseca@mecroc.com.br

Gustavo Antônio Pereira Batista
AngloGold Ashanti, Crixás – GO, Brazil, GABatista@anglogoldashanti.com.br

Gérson Rincon Ribeiro
AngloGold Ashanti, Crixás – GO, Brazil, GRRibeiro@anglogoldashanti.com.br

SUMMARY: The Time Domain Reflectometry (TDR) approach employed in this study is an electrical pulse testing technique originally developed to locate faults in coaxial power transmission cables. When openings are excavated in a rock or soil mass, stresses may exceed the in-situ strength resulting in displacements as unstable blocks move. Coaxial cables are grouted into a rock mass which is expected to cave. Rock movement deforms the cable and produces changes in TDR pulse reflection signatures. By monitoring changes in these reflection waves, it is possible to monitor both extension and shearing.
This paper aims to present how this instrumentation technology was applied to the drill drive of on an underground gold mine in Brazil to monitor stability of the crown pillar. The technique proved to be quite economical because of the ease of installation, use of commercially available instruments and cable, and the ease of data acquisition and interpretation.

KEYWORDS: Time Domain Reflectometry, TDR, Field Instrumentation, Displacements, Discontinuities, Crown Pillar.

1 INTRODUCTION

The Time Domain Reflectometry approach (TDR) employed in this study was initially developed as a method to locate faults or breakdown in coaxial transmission cables (Moflitt, 1964). The concept was expanded to other applications such as the measurement of material properties, such as soil water content (Topp, Davis, & Annan, 1980). In rock mechanics specifically, the technique was used to identify areas of deformation or localized ruptures of the rock mass corresponding to the cable failure sites (O'Connor & Dowding, 1948) and the effects of detonations (Schmitt & Dick, 1985).

The techniques presented here show how the reflected voltage pulses of the coaxial cable installed in the rock mass can be used to quantify the type and the magnitude of the deformation of this rock mass. The motions of the rock massif deform the cable, locally altering the capacitance of the cable and thus the reflected waveform of the voltage pulse. Thus, by monitoring the changes in these reflection signals continuously, it is possible to monitor the deformation or rupture of the rock mass (Dowding, Su, & O'Connor, 1989).

The monitoring system with TDR is considered economical due to the simplicity of installation, the use of commercially available tools / accessories and cables, as well as the ease of data acquisition and interpretation. The coaxial cable can be installed in place with a conventional diameter drilling limits of 51 and 75 mm. With a single portable reading unit, it can be employed to monitor as many cables as desired and produce a data record (Dowding, et al., 1986).

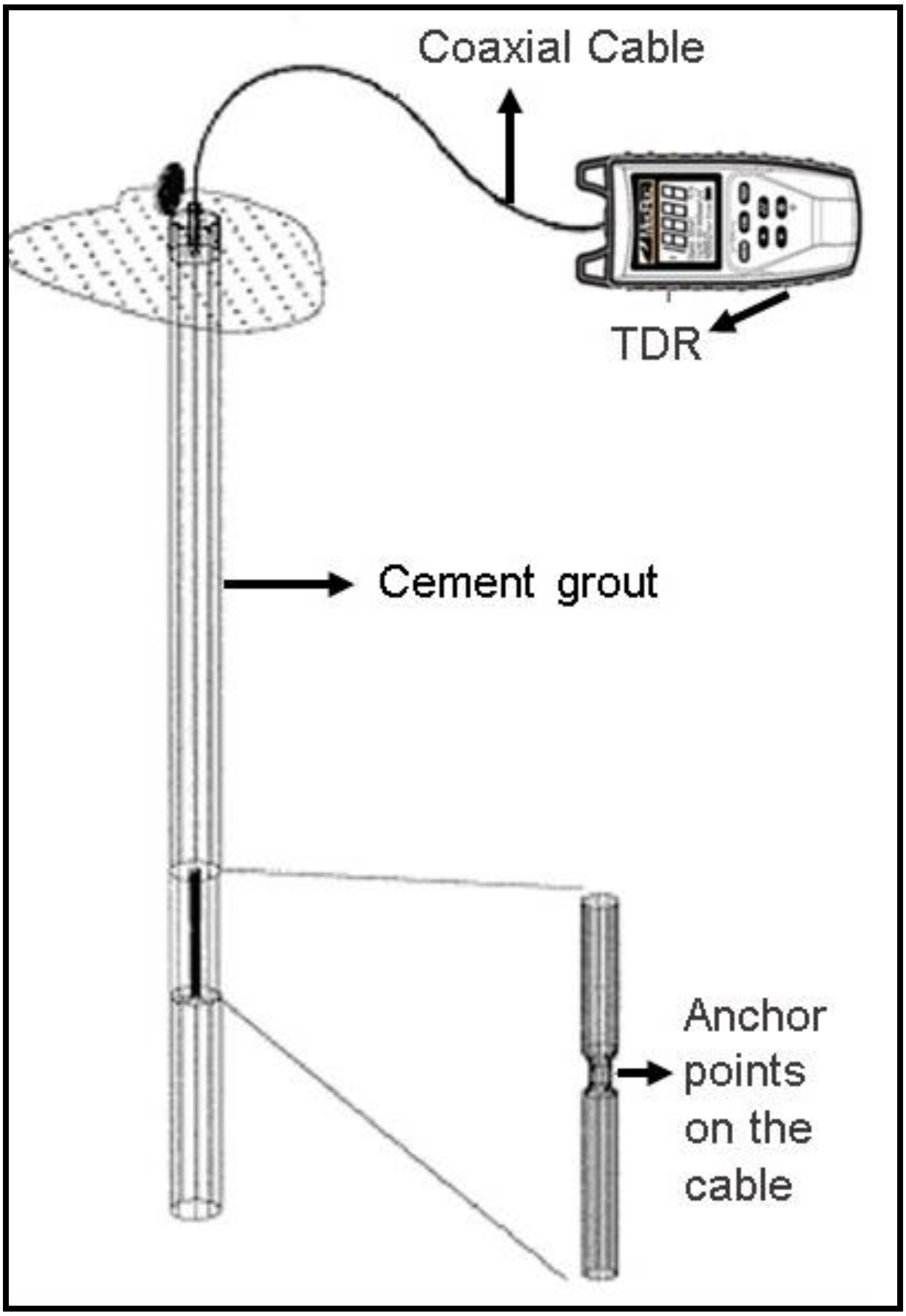


Figure 1. Characteristics of the TDR installation showing the relationship between cable and instrumentation

2 OBJECTIVE OF THE MONITORING

This article presents in detail the use and installation of the Time Domain Reflectometer in geomechanics monitoring and the methodology used for instrumentation of the *INT 354* drill drive located at the Orebody IV of the AngloGold Ashanti Serra Grande Mining. It will be presented from the basic monitoring plan, installation of the system on the field, and application of data collection procedures.

With the main objective of a geomechanical control in the development of the drill drive during the surrounding mining operations. Serra Grande Mining has chosen to use TDR (Time Domain Reflectometry) as a monitoring tool. Figure 2 illustrates the locations where they will be monitored using TDR.

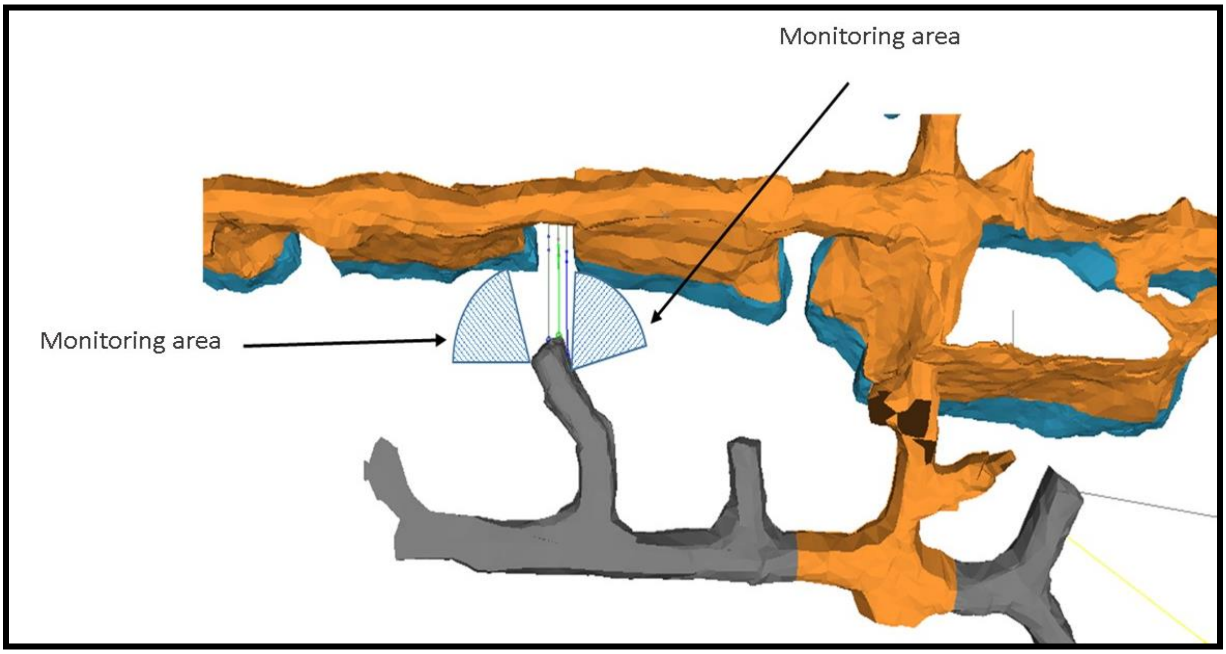


Figure 2. Lay out of the region where the TDR monitoring system is installed

3 EQUIPMENT INSTALLLATION

3.1 AngloGold Ashanti Serra Grande Mining (MSG)

Twelve (12) perforations were performed, these being at level 350 with a diameter of 64mm, on the sides of the drive. The boreholes were divided into six sections of two perforations each, as shown in Figure 3, being one of the boreholes with a slope angle of 30 degrees and another 45 degrees (Figure 4). Six boreholes were drilled for the installation of the TDR cables, as detailed:

- Two cables in section 2;
- A cable in the top hole of section 3;
- A cable in the top hole of section 4;
- One cable in the bottom hole of section 5;
- One cable in the top hole of section 6.

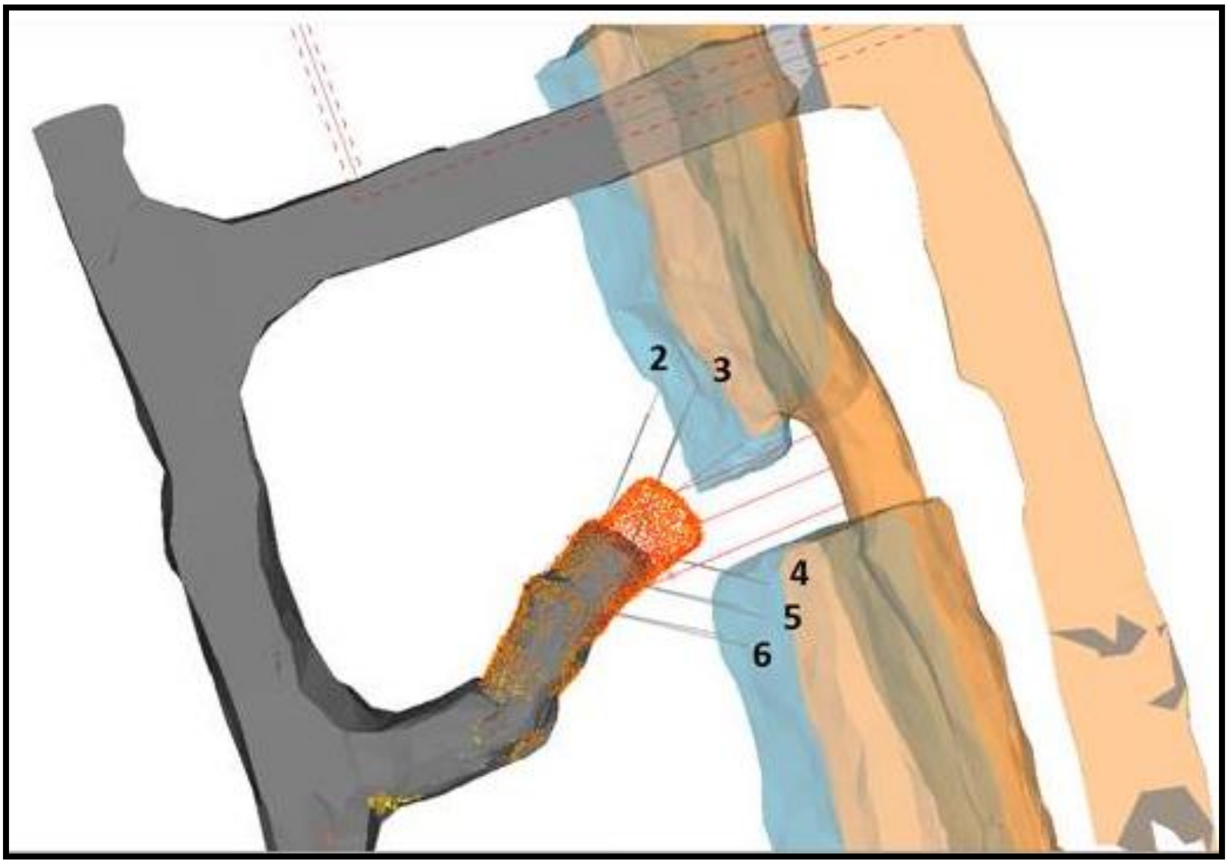
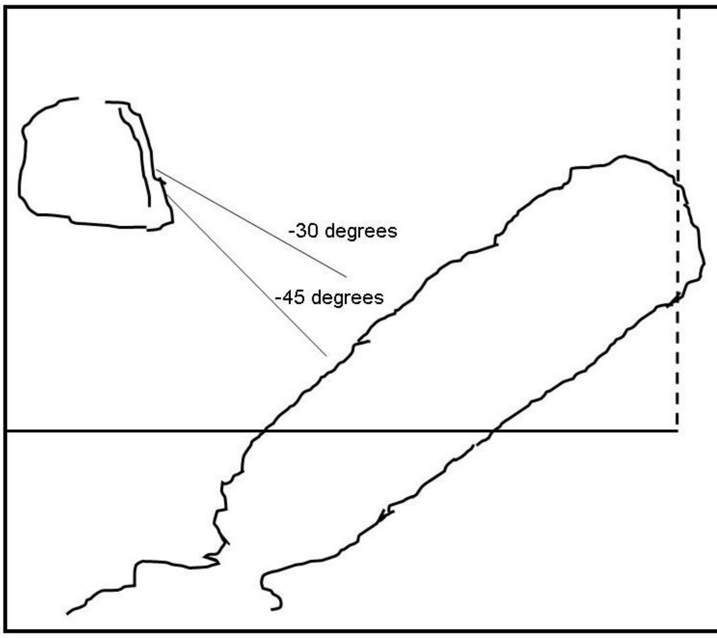


Figure 3. Location of the sections on the sides of the cross-member



Monitoring	Slope Inclination	Length
1	- 30 degrees - 45 degrees	15 meters
2	- 30 degrees - 45 degrees	10 meters
3	- 30 degrees - 45 degrees	8 meters
4	- 30 degrees - 45 degrees	7 meters
5	- 30 degrees - 45 degrees	9 meters
6	- 30 degrees - 45 degrees	10 meters

Figure 4. Perforation plan for each section

Before starting the introduction of the cables into the holes, a profiling was performed using the Reeflex equipment (Figure 5 (a) (b)) and filming with the GatorCam 3+ equipment (Figure 6 (a) (b)), in order to check the possible deviations or identify any particularities.

Figure 5 (a) (b). Equipment used for the perforation profiling.


Figure 6 (a) (b). Equipment used for the perforation filming.

With the data acquired by the equipment it was possible to analyze if the deviations were within an acceptable limit.

Table 1 below shows the identification and length of cables per section.

Table 1 – ID and length of the cables

Section	Cable ID	Length (m)
2	**5551002**	**10,1**
	5551003	**10,0**
3	**5551004**	**8,5**
6	**5551024**	**10,7**
5	**5551025**	**9,5**
4	**5551026**	**7,0**

After defining the depths to be monitored, the cables were prepared, that is, cut in the length, creating roughness in this, with intuition of creating grooves to increase the adherence cable-cement, besides placing clamps spaced in the cable for a better transfer load The next step was to install the BNC connectors on the RGC-213 coaxial cable (Figure 7).

Figure 7. BNC conector installed on the cable

PVC tubes with a 6 mm internal diameter were used as a guide for the introduction of the TDR monitoring cables, and each cable was attached to the tube by means of nylon clamps (Figure 8).

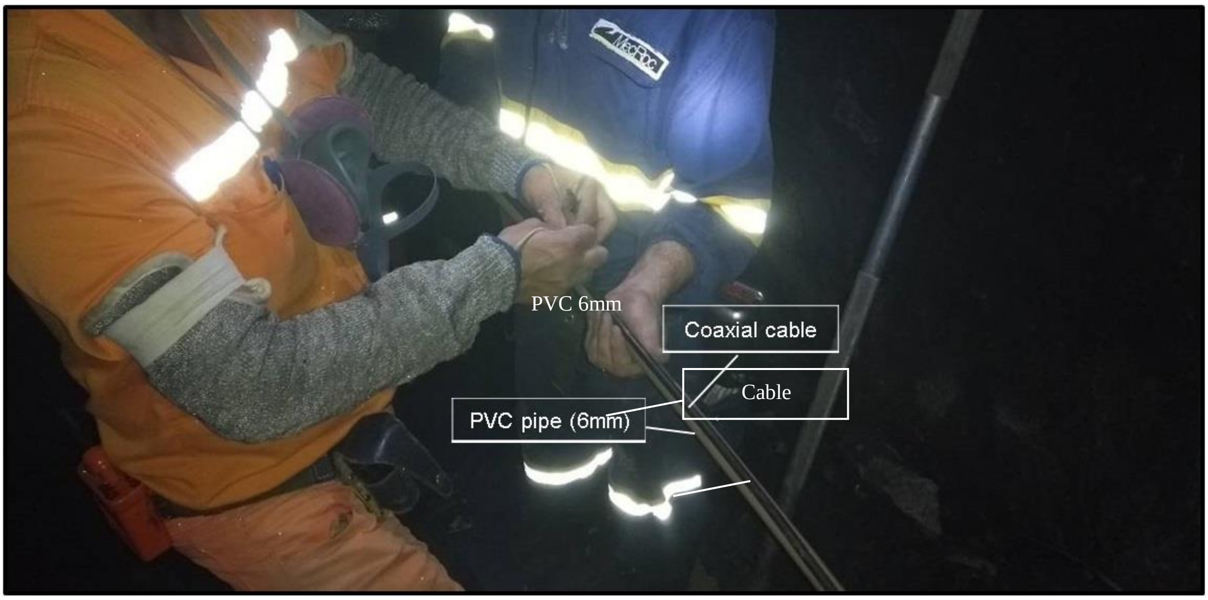


Figure 8. Using clamps to attach the tube to the cable

After the profiling and filming of the holes, the cables attached to the PVC pipes were inserted in the holes, where, to keep them centralized, thicker and reinforced nylon clamps were inserted throughout the PVC pipe intercalating different positions, in this way, the clamps would lean against the wall of the hole, serving as a guide and keeping the cable as centralized as possible (Figure 9).

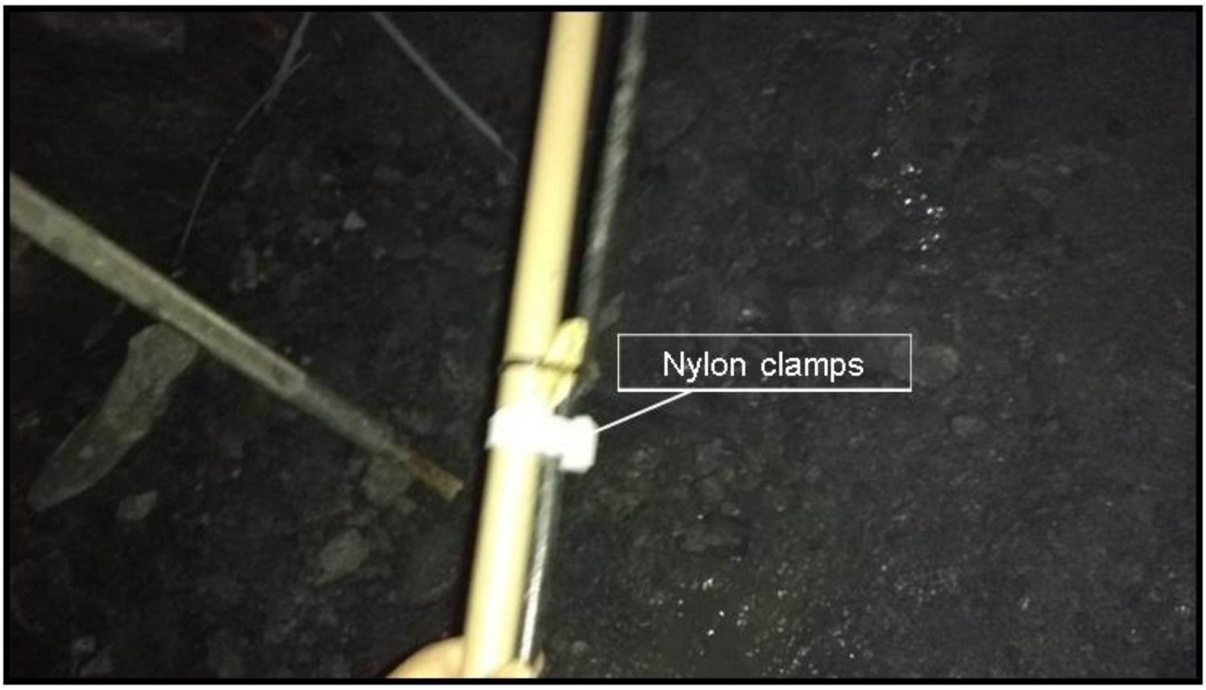


Figure 9. Nylon clamps to help guide and centralize the cable

As the blasting front was program very close to the monitoring cables, it was decided to place the cables as close as possible to the wall of the rock mass to avoid exposure. Therefore, an average of 15 cm of cable was left out of the holes, because this is the minimum length that they could be able to be coupled to the TDR reader at the time of data collection. At the end of the introduction of all the cables, cement was injected by the injection hose removal method, seeking to fill the entire annular space between the cable / tube and the drilling surface. In this way, transferring the effort caused in the rock mass, be it by traction or shear, for the cables. A water / cement ratio of 0.40 was defined (Figure 10).

Figure 10. Cement grouting the cables inserted in the hole

As mentioned, due to detonation being nearby, a tubular steel system, protective (Figure 10) of the cable and accessory was developed. For this reason, it was maintained on average 30 cm without filling of cement grout in the mouth of the hole so that the tubes could be inserted (Figure 11).

Figure 11. Model of the steel protector used to cover the cable heads

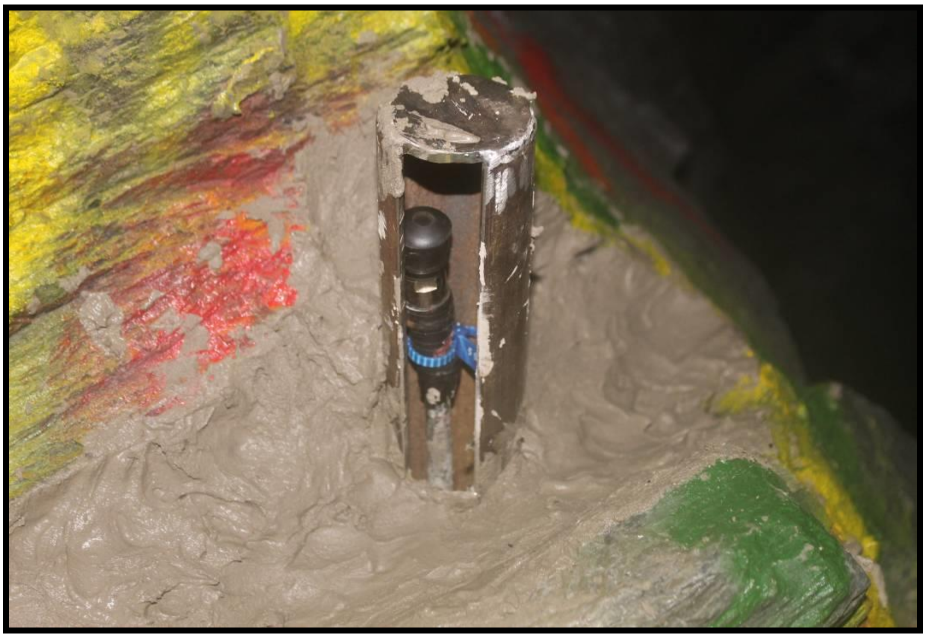


Figure 12. Cable protected after the cover fixed

4 DATA ACQUISITION

After the first rock blasting it was verified that after the rock was cleaned, the section 3 borehole was lost, which was blasted together with the rock and the monitoring cable of section 6 being probably damaged by the machine at the time to perform the cleaning.

A verification and first data collection after the blasting was carried out by the AngloGold Ashanti - Serra Grande operators, as shown in Figure 13, using an Operational Table developed for the team responsible for data collection (Table 2).

Figure 13. Collecting data after the first measurement

Table 2. Model of the Operational Table

AngloGold Ashanti		TDR MONITORING DATA							MecRoc Serviços em Geomecânica e Geotecnia
Site:									
Cable Identification	Date	Shift	Initial Length (m)	Final Length (m)	Cable		Allowance (Yes or No)	Responsible	Observation
					"Open"	"Short"			
5551002									
5551003									
5551004									
5551024									
5551025									
5551026									

5 RESULTS

The blasting and stabilization activities with filling of the mining area occurred in the period from May 18, 2017 to May 6, 2017, during this period the monitoring by Time Domain Reflectometer (TDR) was performed daily, after this period the monitoring became be weekly since activity frequency in the area would be lower.

On May 23, 2017, there was oscillation in three monitoring points (5551002, 5551003 and 5551025). This resulted in the last blasting of the drill drive and varation in the mining area, this rock blasting generated damage on the side of the excavation of up to 0.60m. Monitoring point

5551025 showed another loss of mass at the gallery side of 0.40m, possibly due to some localized instability since monitoring point 5551026 showed no oscillations.

After blasting and filling, transportation activities occurred in the area and the frequency of monitoring became weekly, in the last week in July, the region north of the drill dive had a loss of mass and can be verified by the oscillation of the monitoring points 5551002 and 5551003, the monitoring data shows a lateral rupture of up to 1.4m, the reason for this instability is that it is a blasting in an area close to the monitoring region, possibly the filler does not confine the entire lateral of the gallery and the collapse of that side has occurred and it was confined in the filling.

Below is the monitoring data on the INT-354.

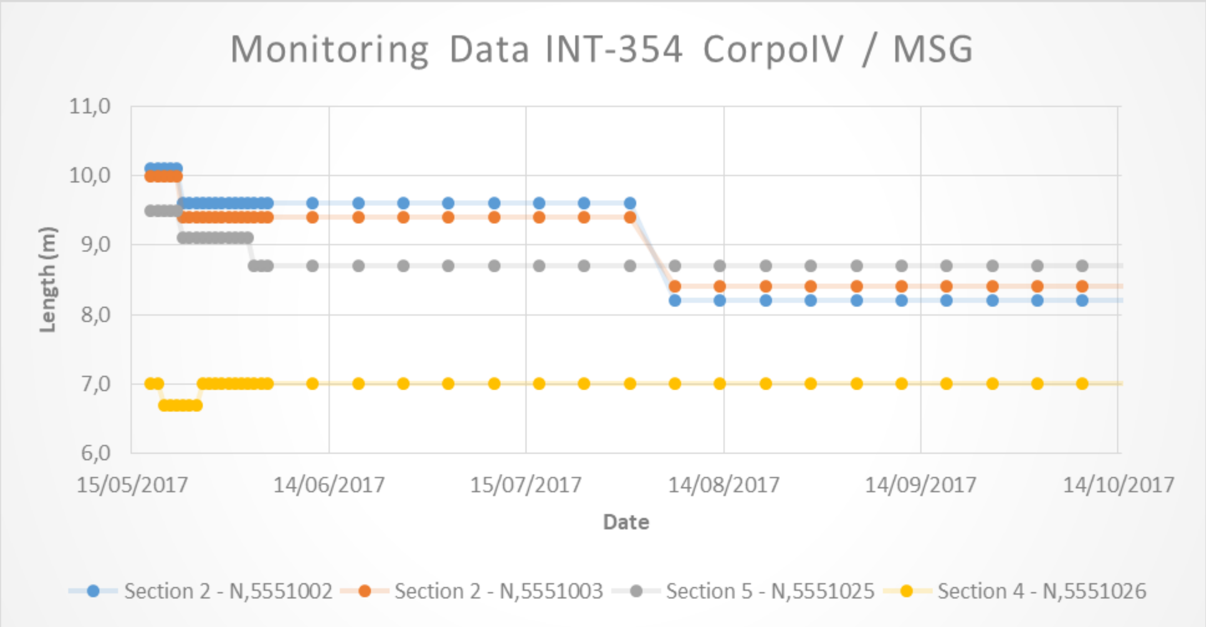


Figure 14. Monitoring Data INT - 354

Due to the fact this data collection is the only one performed it is important to have more quantity and periodicity to create a considerable database, leading to more consistent results in relation to the TDR monitoring, however some findings could already be identified:

- Creation of a monitoring procedure to be carried out by the operators who are working in the area;
- The error of the TDR equipment was significantly decreased using a scaling of the measurements of the NPV ratio given by the equipment with the cable length;
- The TDR geomechanical monitoring was chosen as the most viable alternative for the INT 354 drill drive excavation project, allowing the continuation of mining activities with possible rupture evaluation;
- All instrumented sites have been flagged so no person interferes with monitoring;
- After any blasting carried out on the INT 354 or near the drill drive, access to the drive is prohibited until an adequate person measures the TDR cables;
- Those responsible for rock mechanics, if no anomaly is identified in the measurements, will release the operation to the control room of the mine.

6 CONCLUSIONS AND RECOMMENDATIONS

In situations where important mine accesses are located on and / or around unstable regions, decision makers need a quantitative measure of the probability of occurrence of rupture and to some extent predict and avoid possible accidents with personnel and equipment. In this way,

analyzes with the TDR monitoring system help the team so that the possible negative impacts can be anticipated.
In future unstable monitoring regions, as the length of the coaxial cable is not a limiter, it can be taken to the Ramp, and measurement can be performed through the connector without risk exposure of the involved employees.
It is important to deploy an area release routine since several cables can be installed in different places of the mine, and the same TDR device can perform data collection for all.
This technology has been advanced in such a way that it is possible not only to locate, but also to characterize and quantify displacements of the rock mass by analyzing the changes in the signals.
It is possible, in places of high geomechanical risk, to connect and collect data remotely via optical fiber or radio communication.
Comments should be understood as suggestions for optimization and better use of the monitoring system.

REFERENCES

Dowding, C. H., Su, M. S., O'Connor, K. (1986): Choosing Coaxial Cable for TDR Monitoring. *Proceedings of the 2nd Workshop on Surface Subsidence Due to Underground Mining*, Morgantown, West Virginia, pp. 153--162.

Dowding, C. H., Su, M. B., O'Connor, K. (1989): Principle of Time Domain Reflectometry Applied to Measurement of Rock Mass Deformation, *Int. J. Rock Mech. & Min. Sci*.

Moflitt, L. R. (1964): Time Domain Reflectometry -- Theory and Applications. *Engineering Design News*, November, pp. 38--44.

O'Connor, K. M., Murphy, E. W. (1997): TDR Monitoring as a Component of Subsidence Risk Assessment Over Abandoned Mines. *Int. J. RockMech. & Min. Sci*. 34:3-4, Paper No. 230

O'Connor, K. M., Dowding, C. H. (1984): Application of Time Domain Reflectometry to Mining. *Proceedings of 25th Symposium on Rock Mechanics*, Northwestern University, Evanston, Illinois, pp. 737--746.

Schmitt, G. G., Dick, R. D. (1985): Use of CORRTEX (Continuous Reflectometry for Radius and Time Experiments) to Measure Explosive Performance and Stem Behavior in Oil Share Fragmentation Tests. *Proceedings of the First Mini-Symposium on Explosives and Blasting Research*, Society of Explosives Engineers, Montville, Ohio.

Topp, G. C., Davis, J. C., Annan, A. P. (1980): Electromagnetic Determination of Soil Water Content: Measurements in Coaxial Transmission Lines. *Water Resources Research*, 16 (no. 3), 574--582.