Non-Destructive Integrity Testing of Rock Reinforcement at the Sunrise Dam Mine in Western Australia

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1.0 INTRODUCTION

The traditional pull out tests currently used for rock reinforcement testing is not considered an effective tool for the detection of compromised rockbolt systems used for ground control in underground mining and civil construction industries. Where it is still acknowledged that the pull out test has still an important role to play in determining critical bond lengths for static and quasi static ground support designs, it does not provide an underground operation with any reassurance regarding its rock reinforcement integrity, which could have been compromised during installation or affected by in-situ aggressive conditions. This paper discuss the use of non-destructive technology (i.e. The Mod-Shock System) to identify rock bolts (rock reinforcement) being affected by (i) poor installation techniques (e.g. grouting or resin) (ii) an aggressive underground environment and show signs of corrosion and (iii) ground deformation in excess of rock reinforcement yielding capacity at the Sunrise Dam Gold Mine located in Western Australia.

2.0 BACKGROUND TO THE NON-DESTRUCTIVE INTEGRITY TESTING

In simple terms, the modified shock test [1] is a seismic test using a hammer blow as the force and a transducer to pick up the resultant vibrations With the application of digital filtering techniques an accurate mechanical admittance vs. frequency plot is obtained which can then be interpreted using the concepts developed by Davis & Dunn, 1974 [2].

This non-destructive method by vibration has its origins from Davis and Dunn where they carried out various types of non-destructive pile tests on sites in Western Europe and other French speaking countries for *"The Centre Experimental de Recherches et d'Etudes du Batiment et des Travaux Publics"* (CEBTP) of France. This vibration method had also been used and described by Gardner and Moses [3] in 1973, but this technique had not been exploited by British engineers to the extent that could have been useful to them because of a lack of knowledge of the technique and a degree of mysticism associated with the interpretation of the results.

Since vibration testing of piles was first started by the CEBTP a considerable amount of theoretical work had been done which shed light on interpretation, and the experience of testing many thousands of piles led to the technique being applied with more confidence to piles on sites which lend themselves to being tested in this way. The main function of the test was to detect any major defect such as an open fracture or an important strangulation of the concrete, particularly in the upper portion of the pile [2].

The method is based on measuring the frequency and amplitude response of a rock reinforcement element known as impulse. This response, known as Mechanical Admittance (or mobility), contains all the information necessary to check rock reinforcement integrity and to analyse the surrounding influences. At higher frequencies the resonating harmonics of the rock reinforcement element are detected, whereas at low frequency the response is generally linear allowing measurement of the element-head stiffness.

The non-destructive rock reinforcement integrity testing analysis is conducted using a complex "Stress Wave Analysis" package based on the processing of clear seismic signals imparted into the *rock reinforcement element that* is being tested. The seismic signals are processed by *"Fourier Transform"* into various criteria which can be used to produce models of the element such as mechanical admittance, frequency spectra and velocity which are all being used in the final modelling of the rock reinforcement element under analysis.

In research and laboratory applications of modal analysis, particularly of complex machinery, dynamic excitation was often provided by a linear hydraulic or eccentric mass shaker. Experience gained in testing over 140 bridges indicated that simpler means of excitation are suitable for 90% of all bridges where attaching shakers to bridges were seen as a complex and costly method and is only practical for research purposes or for extremely complex structures [4]. Similarly the application for rock reinforcement integrity testing it was found that a simpler method to excite bolts is adequate for the detection of defects.

The development of the Australian based testing method started in the late 80's and has been used for the correct assessment on a large variety of elements, which now exceeds well over 1,000,000 tests for more than 20 years [5]. Integrity Testing PTY LTD (i.e. developers of the Modshock system) has for over 15 years carried out testing of long length steel rods, either as strand or solid steel bars. The most notable project was for BHP, when they owned the Whyalla steel works where they tested the tie rods holding back the crucial steel pile wall of the coal handling jetty.

The rods were tested and not only were the defective rods identified but it was indicated at what point the rods had lost a large cross section. This was located at a point where the rods came close to the base of the coal handling pit and water was seeping onto the rods causing corrosion. Thus a large successful background in the testing of steel embedded elements, generally with the lengths in excess of 5 meters.

2.1 Test Set-up

There are four components to the system (Figure 1-2):

1. ***A Toughbook / Note book*** **-** this is used to collect data and providing power via a USB cable for the (Figure 1).
2. ***Analogue/Digital Converter*** - this converts the signal from the transducer into a digital format. The converter is soft wired to the transducer (Figure 1).
3. ***Transducer –*** *which is* held at the end of bolt (i.e. collar of hole – see Figure 2) during the test. A signal / pulse is obtained, which is generated by a small hammer.
4. ***A small hammer or tapping device*** (Figure 2) - This has to make contact against the plate of the bolt during the test.

Figure 1 – Annotation of the Modshock system.

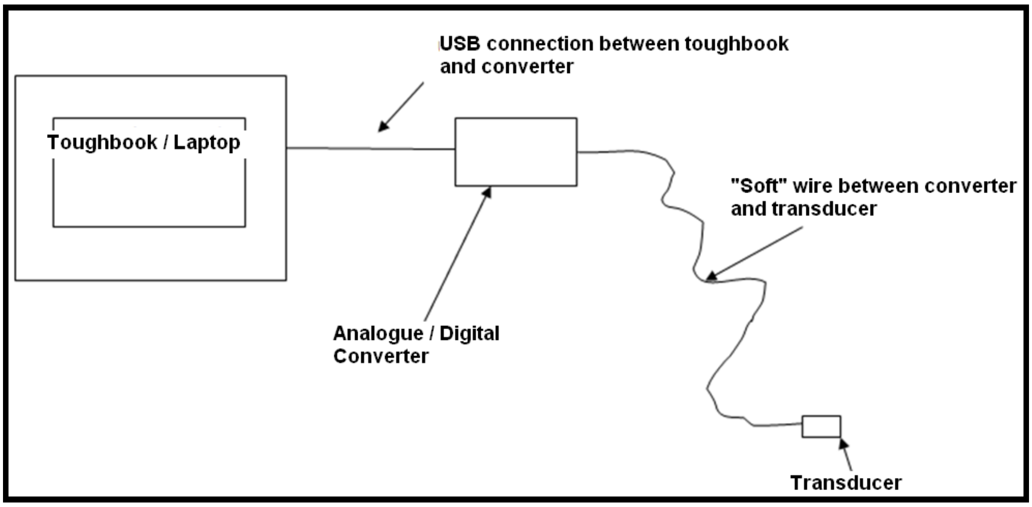


Figure 2 – Transducer and tapping device used to excite (generation of seismic signal) the element.

3.0 CASE STUDY

3.1 Mine Location and Background

The Sunrise Dam Gold Mine (Anglogold Ashanti) is located approximately 200km north-north east of Kalgoorli and 55km south of Laverton in Western Australia (see Figure 3).

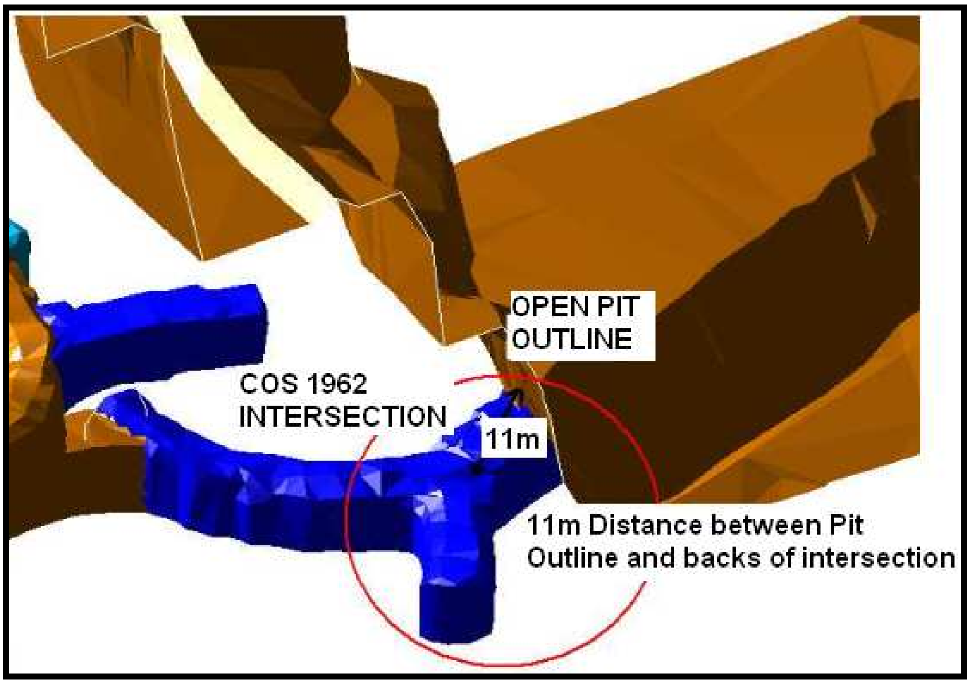
Figure 3 – Sunrise Dam Mine Location (Anglogold Ashanti Annual Report, 2004).

Sunrise Dam comprises a large open-pit and an underground project. Mining is carried out by contractors and ore is treated in a conventional gravity and leach process plant. The underground mine started off small with a resource of 1.6M ounces and 0.5M ounces in reserve in December 2003. Since then Sunrise Dam have mined 367,000 ounces and today the resource is estimated at 12Mt of ore for 2.5M ounces of gold with 6.8Mt for 1.4M ounces of reserves. The ore bodies are generally open at depth and along strike.

The mine develops around 8260m of tunnels per annum and has for the most part 12 headings available during a 24 hour shift. An average of 680m of development per month has been achieved for the period February – August 2009 and it appears that installing ground support at Sunrise Dam Mine is a serious business with around $1.3 million per month assigned to this process. Ground support (i.e. rock reinforcement, mesh and shotcrete) makes up around 34% of the total underground operating costs of which 18% is rock reinforcement (i.e. cable bolt, resin bolt and splitsets). In excess of 150 cable bolts are installed per month, mainly in intersections and ore drives which account for around 3.5% of underground operating costs.

Sunrise Dam Mine as part of their total risk management strategy is looking at various options to improve operating processes and minimising geotechnical risk to the operation. One of these options was assessing the viability in using non-destructive integrity testing as a rock reinforcement quality / integrity management tool. Site testing was conducted between the 23rd and 25th February 2009. The non-destructive testing was intended to assess cable bolts (twin and single strand) and resin bolts (Posimix Bolts) in an area which was located in close proximity of the pit bottom (see Figure 4).

Figure 4 – Test Location 1, Cross section showing COS 1962 intersection's close proximity to open pit bottom.



Two other areas (i.e. Astro 1987 intersection and SSS 1976 ODS) were selected for the non destructive testing of which the cable bolt calibration testing was conducted in the SSS 1976 ODS. COS 1962 intersection (Figure 4) was a critical excavation, as surface water from pit bottom seeping through the backs during testing, made testing conditions very challenging. The ASTRO 1987 intersection were particularly interesting as the ground support installed were found inadequate by mine geotechnical department and new cable bolts were installed as replacement. The SSS 1976 ODS test location comprised of cable bolt calibration test that was completed on the morning of 25th February 2009.

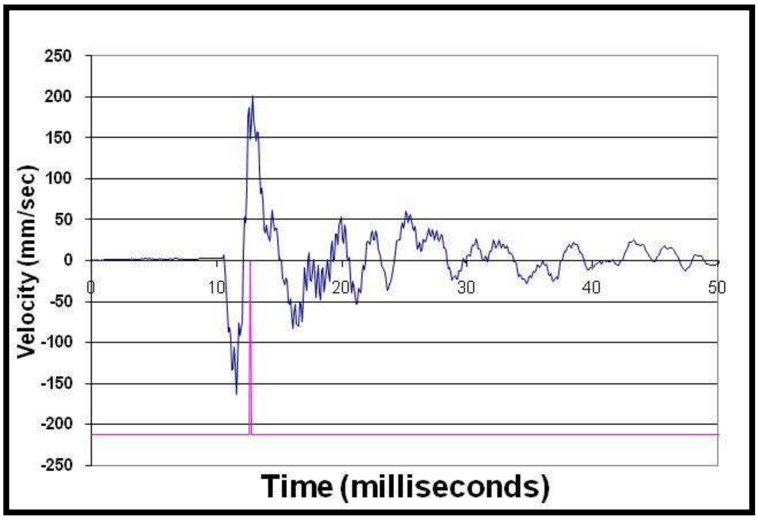
3.2 Calibration testing of 6 twin strand cable bolts at the SSS 1976 OOS

The aim of the calibration testing was to confirm reflection points at areas where grouting have been injected and deliberately stopped at specific locations from the toe end of the bolts as indicated below:

- One 3m Long twin cable bolt –fully encapsulated
- One 4m Long twin cable bolt –fully encapsulated
- One 5m Long twin cable bolt –fully encapsulated
- Three 6m long twin Cable Bolts with 3000mm, 4000mm and 5000mm encapsulation

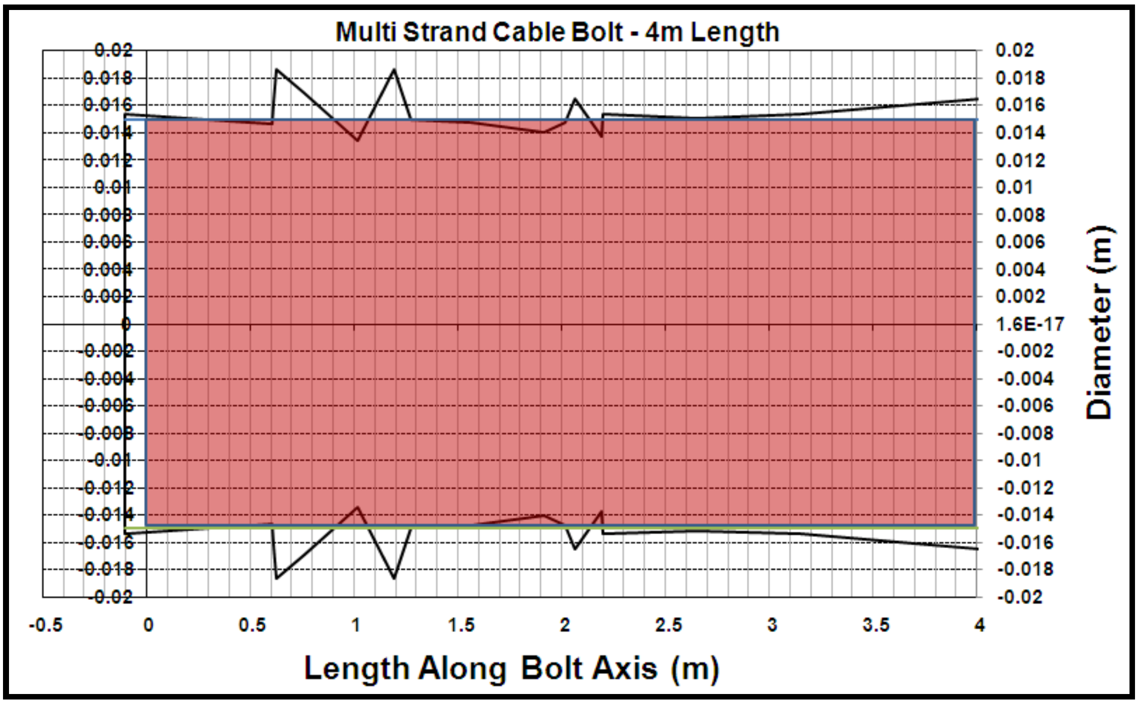
All the signals obtained through the vertical transducer for the non-destructive testing were valid as shown in Figure 5.

Figure 5 – Seismic signal obtained from Test 2 – 4m long full column grouted twin strand cable bolt.



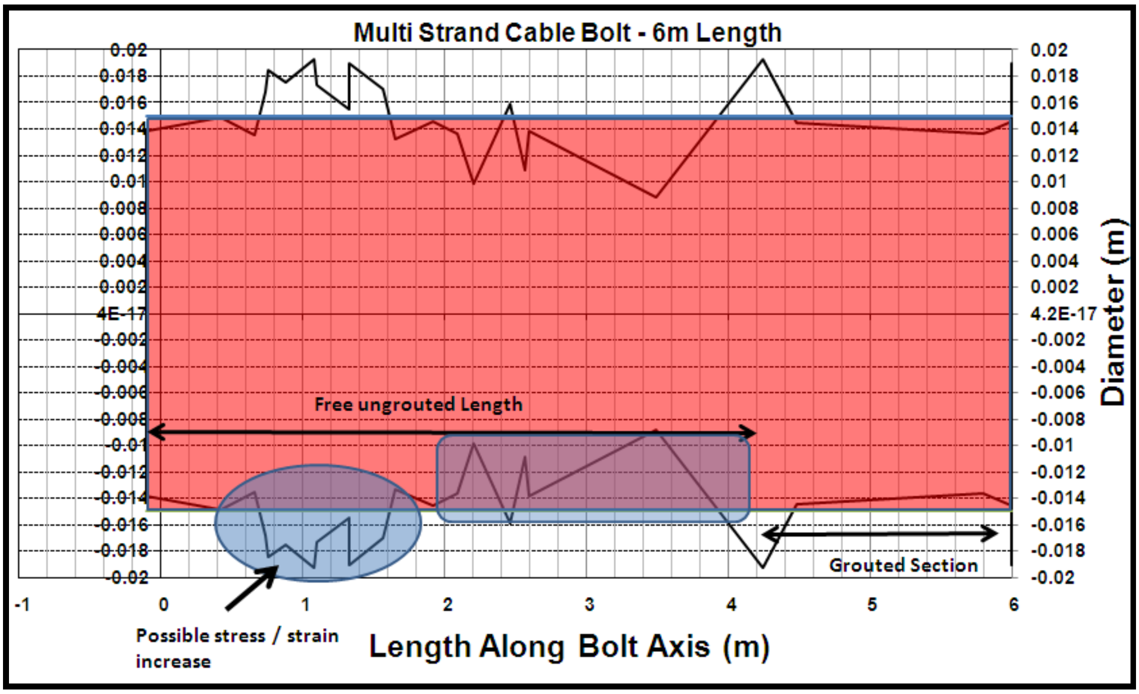
The result for this particular cable bolt calibration test showed that good mechanical admittance and structural stiffness has been achieved throughout the 4m cable bolt length for a full column grouted bolt (see Figure 6) during testing.

Figure 6 – Two dimensional plot with bolt diameter used as control against the length along bolt axis for the 4m long full column grouted twin strand cable bolt.



The above results were compared to the results for the semi controlled partially grouted twin strand cable bolts (see Figure 7 – 6m long twin strand cable bolt proposed grouting between 5 and 6m). This showed a significant reflection and lower structural stiffness.

Figure 7 – Two dimensional plot with bolt diameter used as control against the length along bolt axis for the 6m long partially grouted twin strand cable bolt.



47 Bolts were tested (15 Posimix Bolts and 32 Cable bolts). Of the 15 Posimix bolts tested four showed signs of overstressing (i.e. bolts subject to ground deformation – see Figure 8) and of the 32 Cable Bolts tested three showed signs of overstressing.

Figure 8 – Testbolt 12 at the COS 1962 intersection show slight signs of deformation.

4.0 DISCUSSION

A reduction in load transfer or structural stiffness was noticed in a few of the tests and has been commented on as part of the overall results commentary. The reduction in load transfer between the rock/resin or grout /bolt can be caused by:-

a) Poor mixing techniques,
b) Insufficient resin for the hole size drilled or too large drill tip used
c) Poor ground conditions – soft roof (although this could generally be discounted in this instance)
d) Loss of bolt cross section due to corrosion and subsequent loss in load transfer.

5.0 CONCLUSIONS

Thus the anticipated objective for conducting non-destructive rock reinforcement testing is as follows:

- Verification of current design – this relates to cable bolt anchorage e.g. if the design or selection is for 10m cable bolts and the tests indicates poor anchorage (i.e. a section of around 2m – critical embedment length) or poor load transfer in the 2D mechanical admittance plot as a result of poor grouting and inefficient bonding, it would indicate that the design have been compromised.
- Integrity check of rock reinforcement in main access ways e.g. decline where the bolts need to be intact throughout the life of the excavation – this would then be a check for corrosion (significant volume loss) and/or overstressing where the calculated bolt stiffness is high.
- The third but very important check is for the general quality of ground support installation and this would then become part of the mine's or underground construction's ground support system frequent quality integrity check.

6.0 ACKNOWLEDGEMENT

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