Non Destructive Integrity Testing
Of
Rock Reinforcement Elements at the
Sunrise Dam Mine in Western
Australia

Wouter Hartman
Principal Geotechnical Engineer

B. Lecing, D. Tongue & J. Higgs

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Presentation Layout

- Introduction
- Background to non-destructive testing
- Non-Destructive Testing Set-up and Method
- Test Output
- Case Study
- Conclusions
- Future Work
INTRODUCTION

The traditional pull out tests currently used for rock reinforcement quality control / assessment 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.
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INTRODUCTION (cont.)

It is acknowledged that pull tests have an important role to play in static and quasi static ground support designs in determining critical bond lengths through short anchorage testing. However anchorage capacity testing does not provide an underground operation with any reassurance regarding bolt integrity, which could have been compromised during installation or affected by in-situ aggressive conditions that cause corrosion.
INTRODUCTION (cont.)

HOW WOULD WE REASURE OURSELFS THAT THE QUALITY OF ROCK REINFORCEMENT INSTALLATION IS FOLLOWING GROUND SUPPORT STANDARD SPECIFICATION?

• Ongoing training of personnel and supervision - how effective is that when complacency steps in...?
• Contractor quality management systems ...?
• Audits (very superficial as practice winds down to normal after audit)
INTRODUCTION (cont.)

HOW WOULD WE REASURE OURSELVES THAT THE INTEGRITY OF ROCK REINFORCEMENT IS NOT COMPROMISED THROUGH CORROSION AND SUBSEQUENT BOLT FAILURE WHICH IS NOT IMMEDIATELY DETECTED.
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HOW WOULD WE REASURE OURSELVES THAT THE INTEGRITY OF ROCK REINFORCEMENT IS NOT COMPROMISED THROUGH CORROSION AND SUBSEQUENT BOLT FAILURE WHICH IS NOT NECESSARILY DETECTED IMMEDIATELY.
BACKGROUND TO NON-DESTRUCTIVE INTEGRITY TESTING

In simple terms the modified shock test, which is described by Higgs and Tongue (1999), 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).

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.
BACKGROUND TO NON-DESTRUCTIVE INTEGRITY TESTING

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 (Higgs, 1975). Integrity Testing (i.e. developers of the system) has for over 15 years carried out testing of long length steel rods, either as strand or solid steel bars. Possibly the most notable project being 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.
NON - DESTRUCTIVE TESTING AND SET-UP

There are four components to the system:

(i) **A Toughbook / Notebook** - this is used to collect data and providing power via a USB cable for the analogue/digital converter

(ii) **Analogue/Digital Converter encased in closed unit** - this converts the signal from the transducer into a digital format. The converter is soft wired to the transducer.

(iii) **Transducer** - which is held at the end of bolt (i.e. collar of hole during the test. A signal / pulse is obtained, which is generated by a tapping device / small hammer.

(iv) **The small hammer or tapping device** has to make contact against the plate or nut of the bolt during the test.
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A valid seismic signal is obtained through the Modshock system and is one of the main criteria by which a test is accepted or rejected. The graph displays velocity on the vertical axis and time on the horizontal axis. The blue line represents the seismic signal; whereas the pink line represents the commencement of element analysis.
TEST OUTPUT

One of the vital pieces of information obtained from the non-destructive test is the “Head Stiffness” as this is the basis of all the load predictions and it also indicates the serviceability of the total bolt system. The head stiffness is the “E” prime of the bolt, measured as a direct measurement of the first part of the “structural stiffness plot”, and is similar to a load/displacement graph for a pull out test.

The “bolt head stiffness (tonnes/mm)” is compared to the two model stiffness values “E” min and “E” max. “E” min is a bolt model with the bolt pinned at its toe (end anchored) but with no clamping (no resin or grouting) along its length. “E” max is a bolt model with an infinite rigid base and “clamped” (full column grouted / resin) along its length. These models are based on the work carried out by Davis & Dunn (1974).
TEST OUTPUT

A two dimensional graph is produced where the two opposing curved black lines on the graph represent structural stiffness through good embedment or load transfer. The top (blue) and bottom (green) horizontal lines in the graph collectively represent the element’s full diameter. The structural stiffness presented in the two dimensional plot together with the element’s diameter are used to indicate whether any disturbance e.g. bolt necking, bolt volume reduction through corrosion, bolt shearing and/or ineffective grout or resin embedment) or reflection point can be detected during testing.
CASE STUDY

The Sunrise Dam Gold Mine (Anglogold Ashanti) is located approximately 200km north-north east of Kalgoorlie and 55km south of Laverton in Western Australia.
CASE STUDY

The Sunrise Dam Gold Mine (Anglogold Ashanti) open cut mine.
CASE STUDY

Entrance to underground section of Sunrise Dam Gold Mine (Anglogold Ashanti).
CASE STUDY

• The mine develops around 8260m of tunnels per annum
• 12 headings available during a 24 hour shift
• An average of 680m of development per month achieved February – August 2009
• $1.3 million per month assigned to ground control 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.
CASE STUDY

• Sunrise Dam Mine as part of their total risk management strategy 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.
CASE STUDY
CASE STUDY

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

• 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
CASE STUDY

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

Cable Bolt Installation Movie
CASE STUDY
Seismic signal obtained from Test 2 – 4m long full column grouted twin strand cable bolt
CASE STUDY

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
CASE STUDY

The results for the full column grouted bolt were compared to the results for the semi controlled partially grouted twin strand cable bolts 6m long with grouting located between 5 and 6m. This showed a significant reflection and lower structural stiffness.
CASE STUDY - 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
CASE STUDY

Of the 47 Bolts tested:
- 15 Posimix Bolts
- 32 Cable bolts of which 6 were cable calibration bolts.

Bolts were tested for defects:
- Insufficient grout / resin affecting anchorage;
- Bolts affected by corrosion displaying significant volume loss and reduced load transfer indicating low load transfer or poor encapsulation.

These defects or significant issues were presented through a simplified bolt serviceability classification system:

<table>
<thead>
<tr>
<th>Category</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Category 1</td>
<td>A perfect bolt in perfect rock conditions – in our opinion this will rarely occur</td>
</tr>
<tr>
<td>Category 2</td>
<td>A bolt which we consider is serviceable in that it has good anchorage, good embedment / load transfer along the length of the bolt and reasonable rock/grout/resin contact. Conform to design criteria e.g. end anchored resin bolts.</td>
</tr>
<tr>
<td>Category 3</td>
<td>A bolt that has some deficiencies in reduced anchor strength, poor grout/resin/rock contact or loss of bolt section. The remarks section will identify the possible source of the deficiency.</td>
</tr>
<tr>
<td>Category 4</td>
<td>A bolt that has either failed; is loose or at a point where additional load on the bolt could lead to failure; or a loss of bolt section which is critical e.g. anchorage area where the 400mm critical bond length has been affected</td>
</tr>
</tbody>
</table>

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CASE STUDY - RESULTS

The table below shows a distribution of the serviceability classification categories.

<table>
<thead>
<tr>
<th>Categories</th>
<th>COS 1962</th>
<th>ASTRO 1987</th>
<th>Calibration</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Posimix Bolts</td>
<td>Cable Bolts</td>
<td>Cable Bolts</td>
</tr>
<tr>
<td>Category 2.</td>
<td>3</td>
<td>2</td>
<td>4</td>
</tr>
<tr>
<td>Category 3.</td>
<td>4</td>
<td>1</td>
<td>5</td>
</tr>
<tr>
<td>Category 4.</td>
<td>7</td>
<td>4</td>
<td>5</td>
</tr>
</tbody>
</table>
CASE STUDY

• A reduction in load transfer was noticed in a few of the tests

• 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) Loss of bolt cross section due to corrosion and subsequent loss in load transfer.
CONCLUSION

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.
CONCLUSION (Cont.)

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

• 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.
CONCLUSION (Cont.)

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

• 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.
FUTURE WORK

We acknowledge that we need to conduct the following work to increase confidence in other data interpretation:

- Calibration testing to confirm the elastic load increase in tendons and solid rebars
ACKNOWLEDGEMENTS

• Mr. Lammie Nienaber – Senior Geotechnical Engineer (Sunrise Dam Gold Mine – Anglogold Ashanti)
• Sunrise Dam Mine Management for allowing us to publish the results
Questions...?