Managing Geotechnical Risk Through Non-Destructive Rock Reinforcement Testing Trialed at the George Fisher Mine, Mt Isa

Wouter Hartman
Principal Geotechnical Engineer

B. Lecing, F.Harvey, D. Tongue & J. Higgs

Second Australian Ground Control in Mining Conference
Sydney, UNSW, Australia
23th November 2010

Integrity Testing Pty Ltd

GEOHART CONSULTANTS
Geotechnical *(Mining & Civil)*

Freyssinet

Presentation Layout

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

INTRODUCTION

“Risk management plays a major role in the day to day mining operations at GFM – A Quote which the authors were in strong agreement - It is called First Principle of Risk Assessment:

"Before you can MANAGE something, you must first be able to MEASURE it."

As a risk assessor, you have to be able to measure the risks and provide that information to mine management.

If you cannot measure something, how will you even know if you are actually managing anything?”

Paper - Mine Wide Risk Assessment – What is the State of your Arteries

L.Human, J Doolan and L Potts ***– Xstrata Zinc:*** *Queensland Mining Industry Health and Safety Conference 2006*

Integrity Testing Pty Ltd

GEOHART CONSULTANTS

Geotechnical *(Mining & Civil)*

Freyssinet

INTRODUCTION (cont)

So how do we measure the potential for a rockfall if we as geotechnical / rock mechanics engineers want the ground to be secure..?

By definition: Secure ground is ground that is supported (surface support and rock reinforcement) in accordance with the **ground control management plan** – i.e. following an appropriately implemented standard.

and

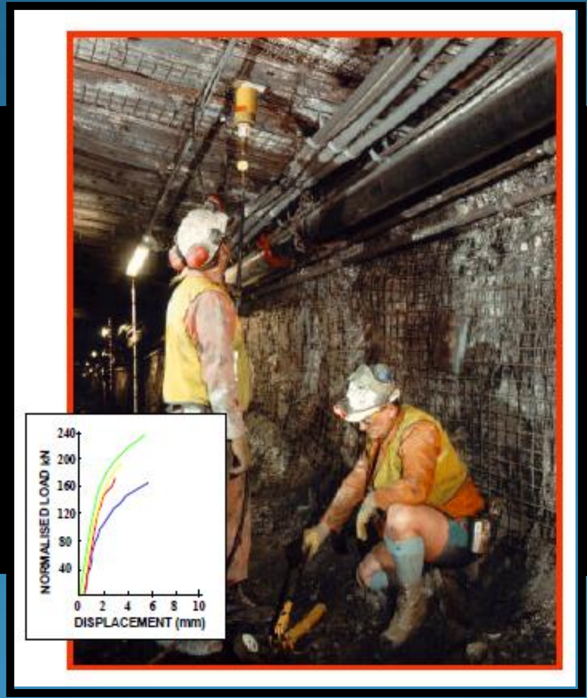
"Rock reinforcement should be quality controlled on a regular basis through ad hoc pull testing"

INTRODUCTION (Cont)

2004

2009

1990



The traditional pull out tests currently used for rock reinforcement quality control / assessment testing is not considered an effective tool for the effective measurement or detection of compromised rockbolt systems used for ground control in mining!!!.

Integrity Testing Pty Ltd

GEOHART CONSULTANTS

Geotechnical *(Mining & Civil)*

Freyssinet

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.

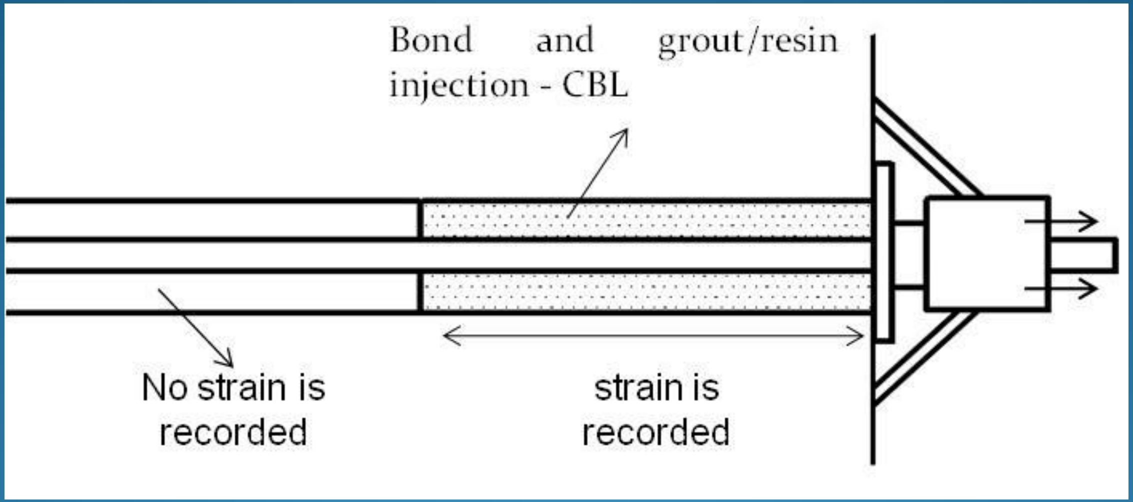
What Does It Mean?

INTRODUCTION (Cont)

Standard Test Method for Rock Bolt Anchor Pull Test

•The objective of this test method is to measure the working and ultimate capacities of a rock bolt anchor. This method does not measure the entire roof support system. This method also does not include tests for pre-tensioned bolts or mine roof support system evaluation. (2008, ASTM Committee)

PULL OUT TEST MECHANISM

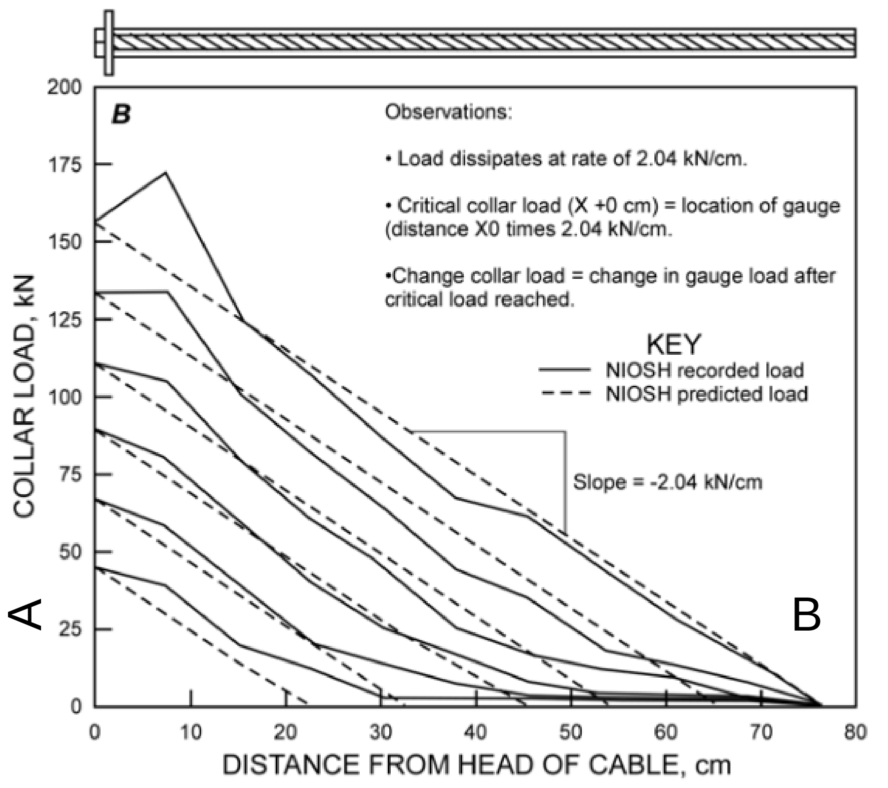


CBL – Critical Bond Length of grout / resin which result in bolt yield when subject to loading

- **Resin bolt = ± 300-500mm**
- **Twin strand cable = ± 900-1100mm**
- **Single strand cable = ± 1400-1600mm**

INTRODUCTION (Cont)

Collar load plotted against A, microstrain (load profile curve) and B, distance from head of cable (load correlation curve, Martin et al (2004)).



In 2004 Martin et al. showed that a critical load is required before the cable bolt, at a given location, would sense any load. This was done through instrumented cable bolts loaded at the collar and plotted against recorded microstrain at individual gauge locations (The load profile along the length of the cable at different collar loads). This implied that a gauge positioned 25.4 cm from the collar would sense load only when the collar load exceeds 25.4 × 2,043 N/cm.

INTRODUCTION (cont.)

SO 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)

Integrity Testing Pty Ltd

GEOHART CONSULTANTS

Geotechnical *(Mining & Civil)*

Freyssinet

INTRODUCTION (cont.)

HOW WOULD WE REASURE OURSELFS THAT THE INTEGRITY OF ROCK REINFORCEMENT IS NOT COMPROMISED THROUGH CORROSION AND SUBSEQUENT BOLT FAILURE WHICH IS NOT IMMEDIATELY DETECTED.

Perhaps proven non destructive means would be the way forward

Integrity Testing Pty Ltd

GEOHART CONSULTANTS

Geotechnical *(Mining & Civil)*

Freyssinet

BACKGROUND TO NON-DESTRUCTIVE INTEGRITY TESTING

Buys (2008) found that studies to develop non-destructive testing methods to determine a rock bolt's integrity have been conducted since 1977.

List of Non Destructive Testing Methods

- Boltometer
- JK rockbolt tester
- GRANIT
- Ultrasonic Guide Wave Testing

Non Destructive Testing Methods

- Boltometer – Instrument can be used on cemented grouted bolts and also on polyester and some other grouts.

- JK rockbolt tester – This method is based on the measurement and analysis of the complete dynamic response of the bolt.

- GRANIT – The ground anchorage integrity testing (GRANIT) system applies an impulse of known force by means of an impact device that is attached to the tendons.

- Ultrasonic Guide Wave Testing – It is based on an ultrasonic pulse echo test carried out from the free end of the bolt

BACKGROUND TO NON-DESTRUCTIVE INTEGRITY TESTING

Buys critically reviewed the previously listed methods and highlighted their respective limitations.

Non Destructive Testing Methods

- **Boltometer** – Boltometer can indicate bad ground, but if the impedance between the grout and surrounding rock are the same; wave energy will dissipate into the rock before it could reach a major defect, reporting good grouting.

- **JK rockbolt tester** – Resonant frequencies and associated damping ratios are primarily determined by the mechanical characteristics of the bolt in situ, resin grout and the rock.

- **GRANIT** – The disadvantage of this system is that it can only work on rock bolts that have been charaterised at installation.

- **Ultrasonic Guide Wave Testing** – The low frequency test can be used to identify defects such as partial bolt encapsulation and possibly corrosion patches near the bolt surface. The high frequency test is not sensitive to **surface defects**, but can give a reliable indication of the bolt length.

Integrity Testing Pty Ltd

GEOHART CONSULTANTS

Geotechnical *(Mining & Civil)*

Freyssinet

BACKGROUND TO MODSHOCK SYSTEM

The MODSHOCK system used within the testing program at the George Fischer mine compared to the previous mentioned systems is relatively simple in operation. In simple terms, the modified shock test as 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.

LIMITATION TO THE MODSHOCK SYSTEM

Poorly tightened nuts and plates or loosened nuts and plates which makes the retrieval of valid signal difficult.

MODSHOCK TESTING AND SET-UP

<u>There are four components to the system:</u>

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

MODSHOCK TESTING AND SET-UP

<u>There are four components to the system:</u>

- *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 .

Integrity Testing Pty Ltd

GEOHART CONSULTANTS

Geotechnical *(Mining & Civil)*

Freyssinet

MODSHOCK TESTING AND SET-UP

There are four components to the system:

- *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.

Integrity Testing Pty Ltd

GEOHART CONSULTANTS

Geotechnical *(Mining & Civil)*

Freyssinet

MODSHOCK TESTING AND SET-UP

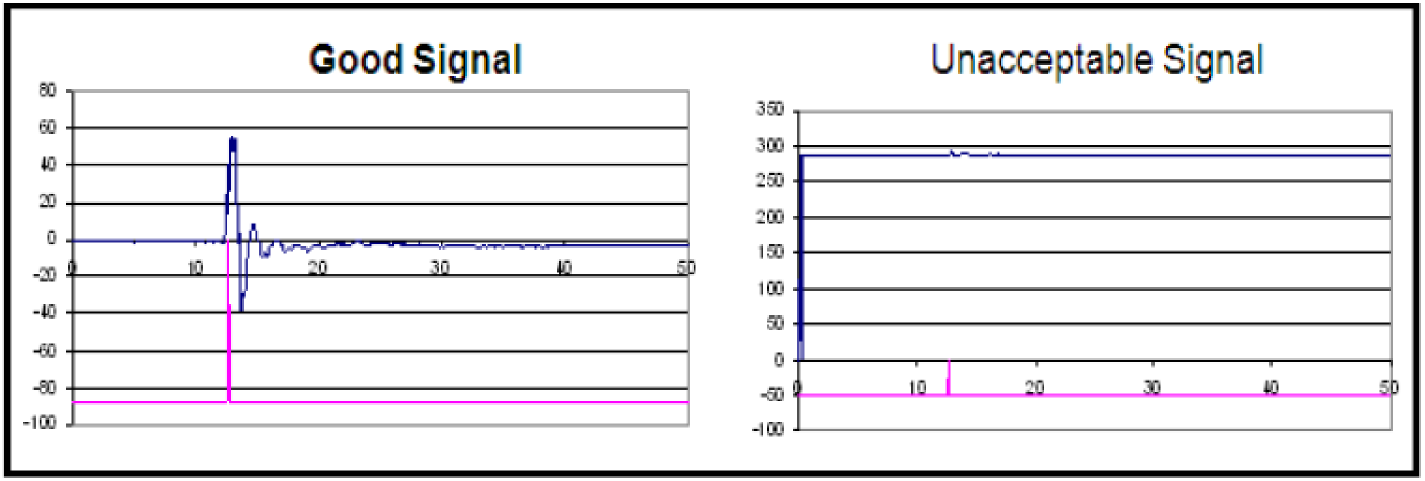
<u>There are four components to the system:</u>

- ***The small hammer or tapping device*** has to make contact against the plate or nut of the bolt during the test.

TEST OUTPUT

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.

Two graphs showing the difference between a good signal obtained and an unacceptable signal.



Integrity Testing Pty Ltd

GEOHART CONSULTANTS

Geotechnical *(Mining & Civil)*

Freyssinet

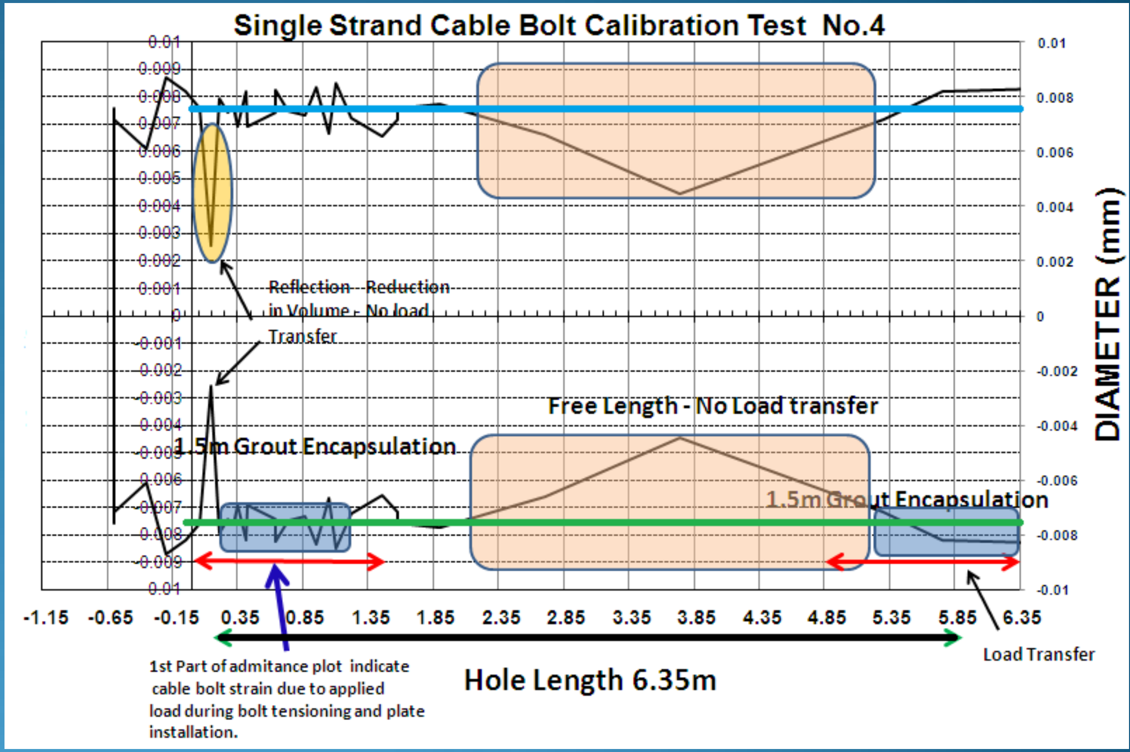
TEST OUTPUT

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.



Integrity Testing Pty Ltd

GEOHART CONSULTANTS

Geotechnical *(Mining & Civil)*

Freyssinet

CASE STUDY

The George Fisher Mine (lead, zinc and silver) is located 20km north of Mt. Isa and over 950 km west of Townsville in North Queensland.

Integrity Testing Pty Ltd

GEOHART CONSULTANTS

Geotechnical *(Mining & Civil)*

Freyssinet

CASE STUDY

- George Fisher Mine as part of their total risk management strategy looked 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 on the 8th and 16th September 2009. The non-destructive testing was intended to assess cable bolts (twin and single strand), resin bolts (Posimix Bolts) and friction bolts (47mm diameter).

CASE STUDY

- 6 Level 5053 EXC – Calibration Tests for Cable Bolts, Resin bolts and Friction Bolts.

- 16 Level – Tests for grouted and resin solid bars (Test results not part of this presentation).

Integrity Testing Pty Ltd

GEOHART CONSULTANTS

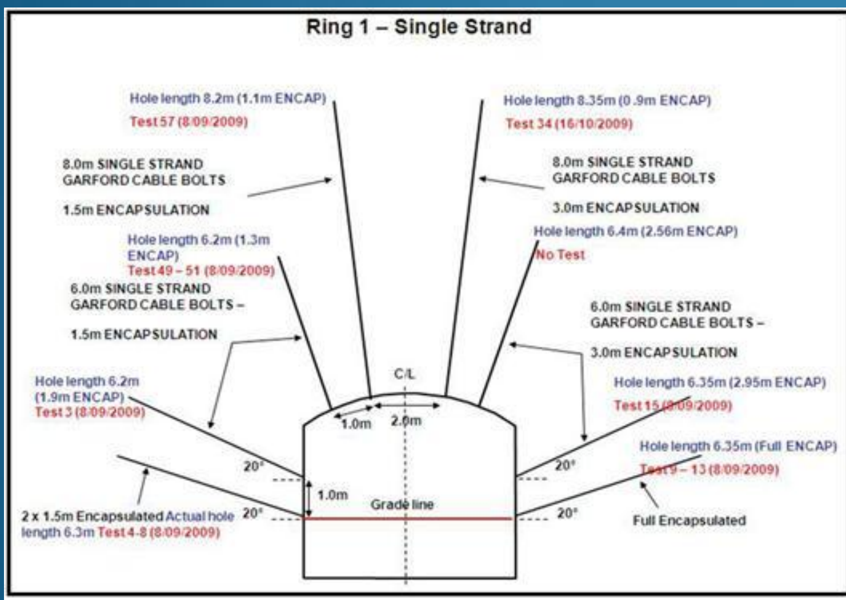
Geotechnical *(Mining & Civil)*

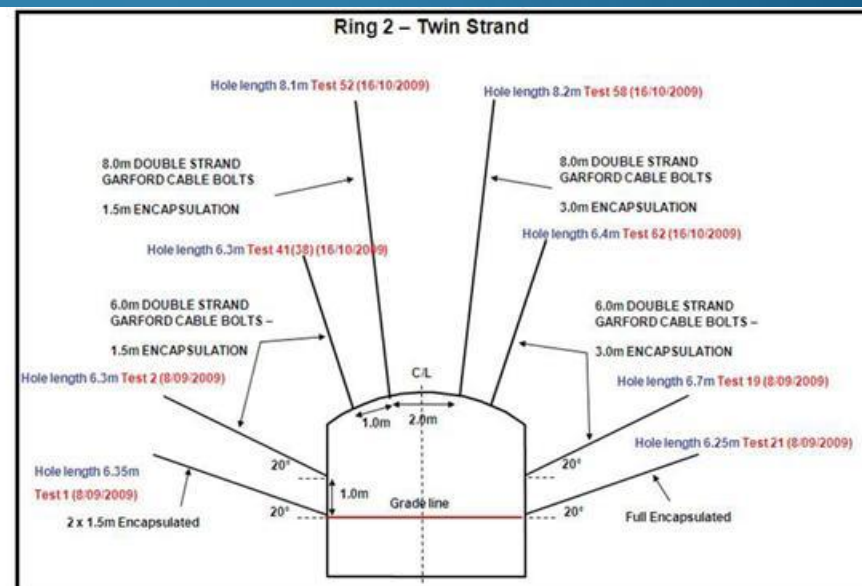
Freyssinet

CASE STUDY

Calibration testing program at George Fisher Mine consisted of:

i. Cable Bolts
   - 6m and 8m Single Strand Cable Bolts – One bulb per meter.
   - 6m and 8m Twin Strand Cable Bolts - One bulb per meter.



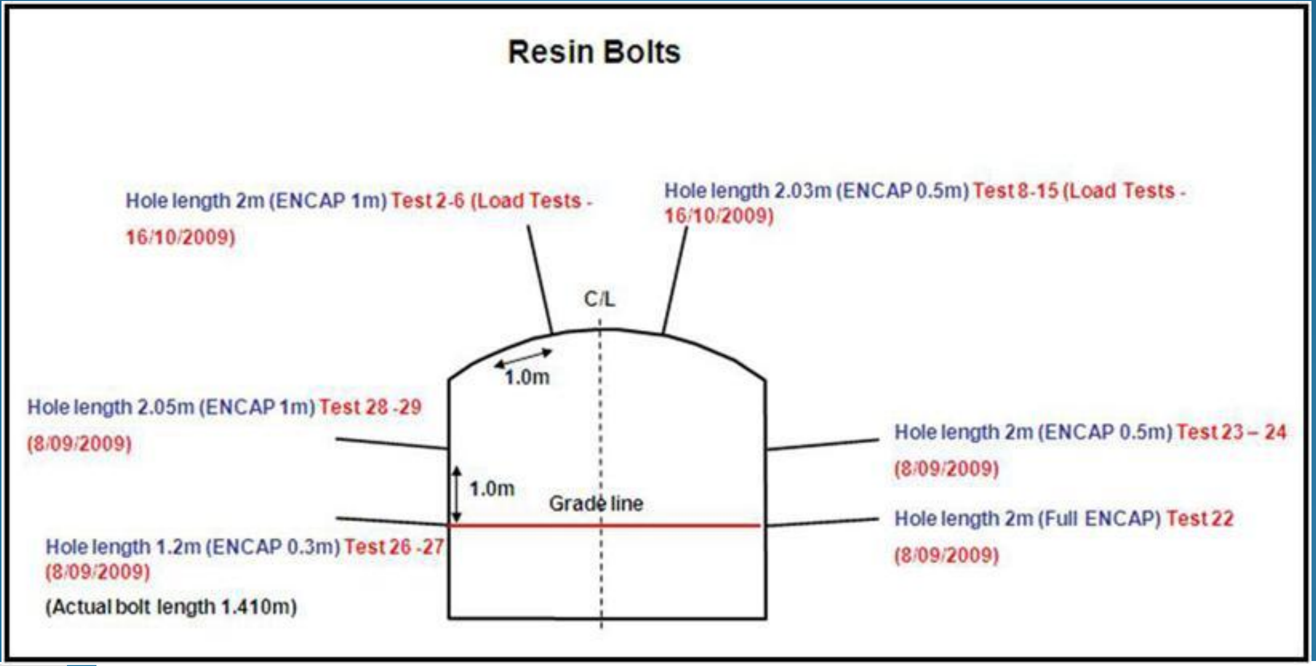


CASE STUDY

Calibration testing program at George Fisher Mine consisted of:

ii. Resin Bolts

- 2.2m Thread Bar Posimix.



Integrity Testing Pty Ltd

GEOHART CONSULTANTS

Geotechnical *(Mining & Civil)*

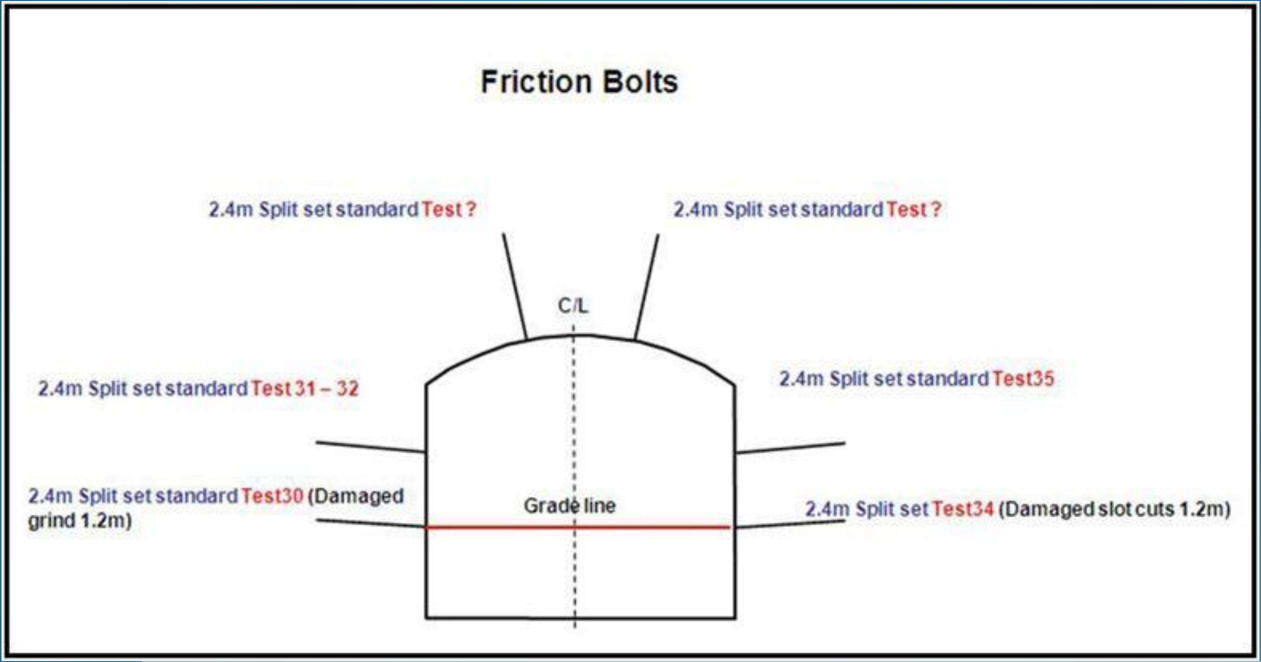
Freyssinet

CASE STUDY

Calibration testing program at George Fisher Mine consisted of:

iii. Friction Stabiliser Bolts

- 2.4m Friction Bolt, 47mm diameter.



Integrity Testing Pty Ltd

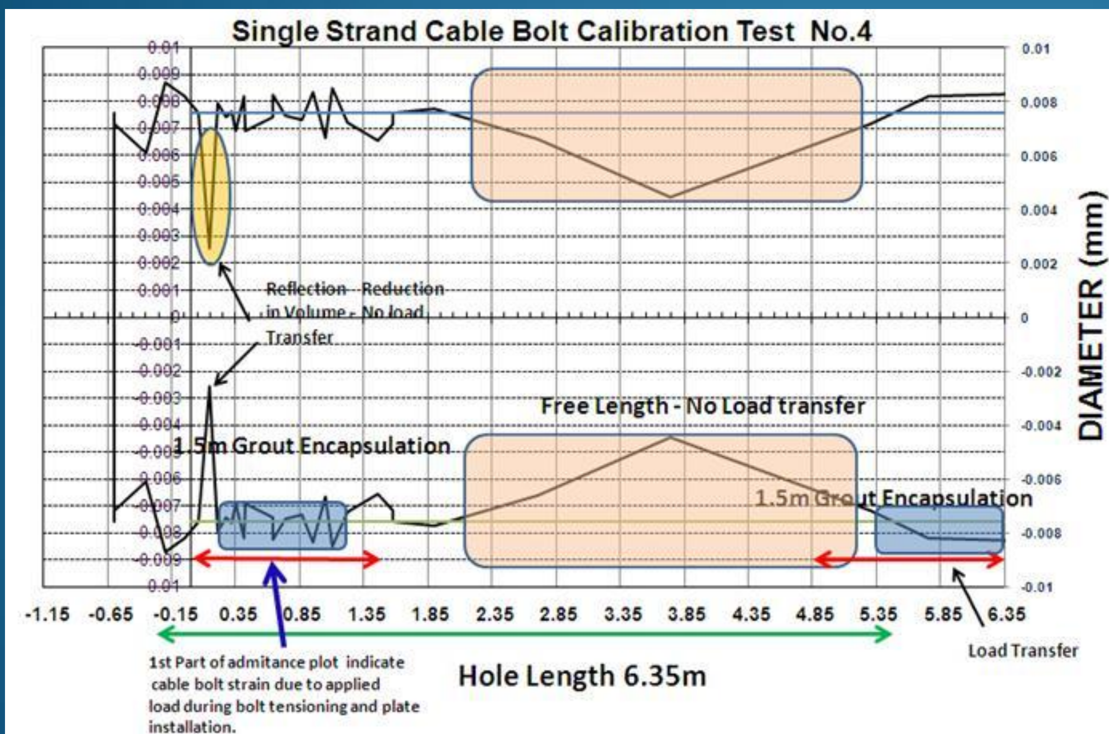
GEOHART CONSULTANTS

Geotechnical *(Mining & Civil)*

Freyssinet

RESULTS

Results - Two dimensional plot with bolt diameter used as control against the length along bolt axis for the 6m long (2 x 1.5m encapsulated) single strand cable bolt, Test No.4.



The test results showed that the grouting of the toe and collar with a centre free length was clearly detected using the Modshock system. The anticipated grout location of 1.5m away from the toe and collar could not be accurately picked as the location of the grout appears to be slightly different that what has been proposed. This could very well be a sign of the lack of control during the grout installation.

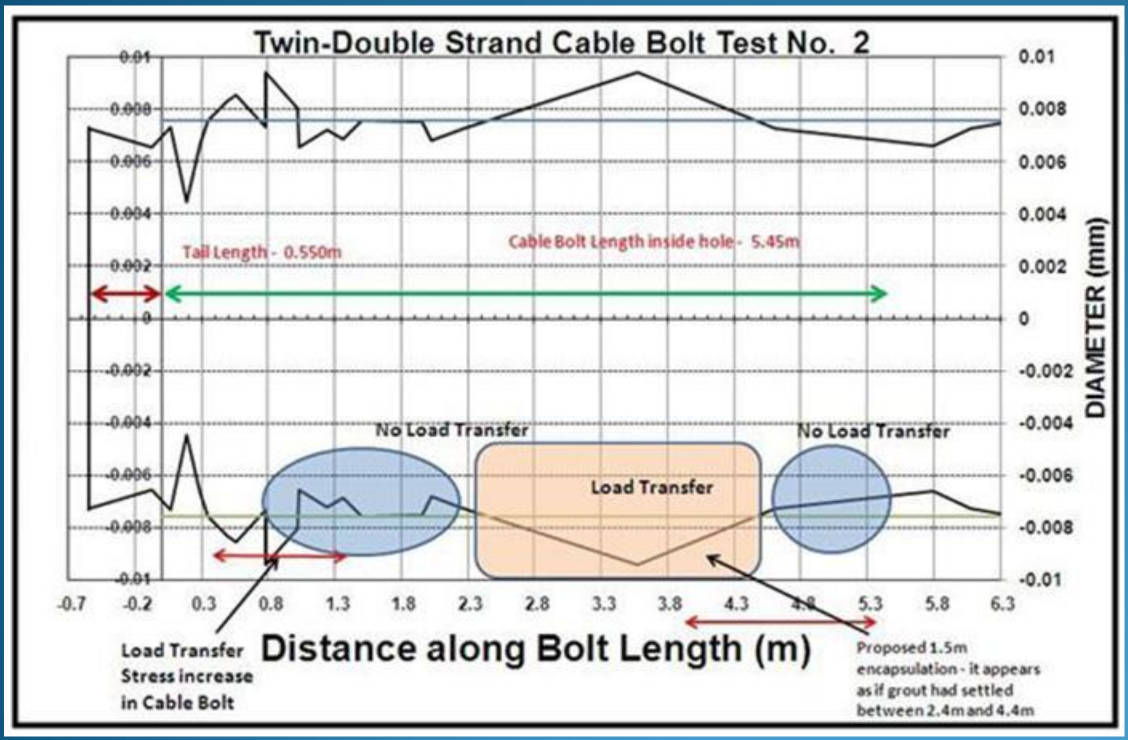
Integrity Testing Pty Ltd

GEOHART CONSULTANTS

Geotechnical *(Mining & Civil)*

Freyssinet

Results - Two dimensional plot with bolt diameter used as control against the length along bolt axis for the 6m long (1.5m encapsulated) twin strand cable bolt, Test No.2.



results showed that the grouting of the toe and free length towards the collar was clearly detected using the Modshock system. The 6.0m long cable had a 0.550m tail and 5.45m length inside the hole. The anticipated grout embedment length of 1.5m appears to cover a much larger area (i.e. 2.0m – 2.4 to 4.4m) than what was proposed (i.e. an area of load transfer). The test result also suggests a gap towards the end of the hole

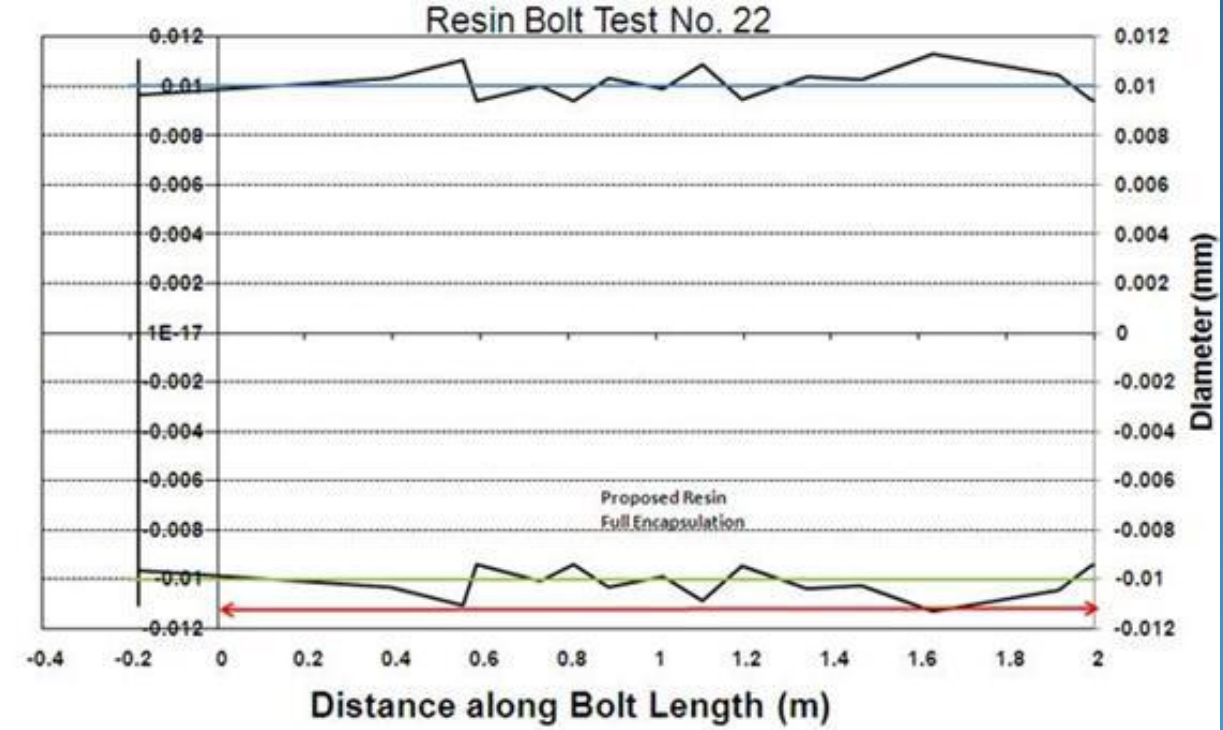
Integrity Testing Pty Ltd

GEOHART CONSULTANTS

Geotechnical (Mining & Civil)

Freyssinet

Results - Two dimensional plot with bolt diameter used as control against the length along bolt axis for the 2.2m long (fully encapsulated) resin bolt, Test No.22.



The 2D mechanical admittance plot clearly shows this to be the case with load transfer throughout the length of the bolt. This bolt will thus be classified as a serviceable bolt with good anchorage

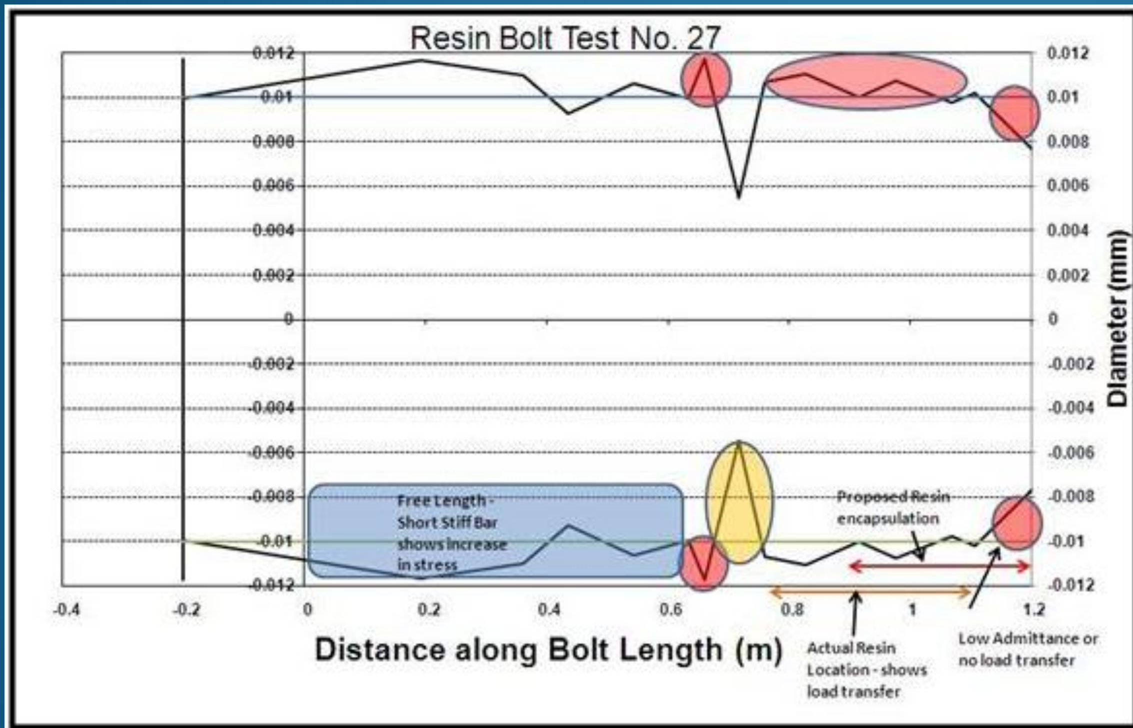
Integrity Testing Pty Ltd

GEOHART CONSULTANTS

Geotechnical *(Mining & Civil)*

Freyssinet

Results - Two dimensional plot with bolt diameter used as control against the length along bolt axis for the 1.4m long (0.3m encapsulated) resin bolt, Test No.27.



Results show clearly areas of load transfer and / or mechanical admittance. It is recognised that through the initial review the bolt appeared to be the full 2.2m length. However two significant reflection points showed a no load transfer or discontinued admittance in the 2D plot

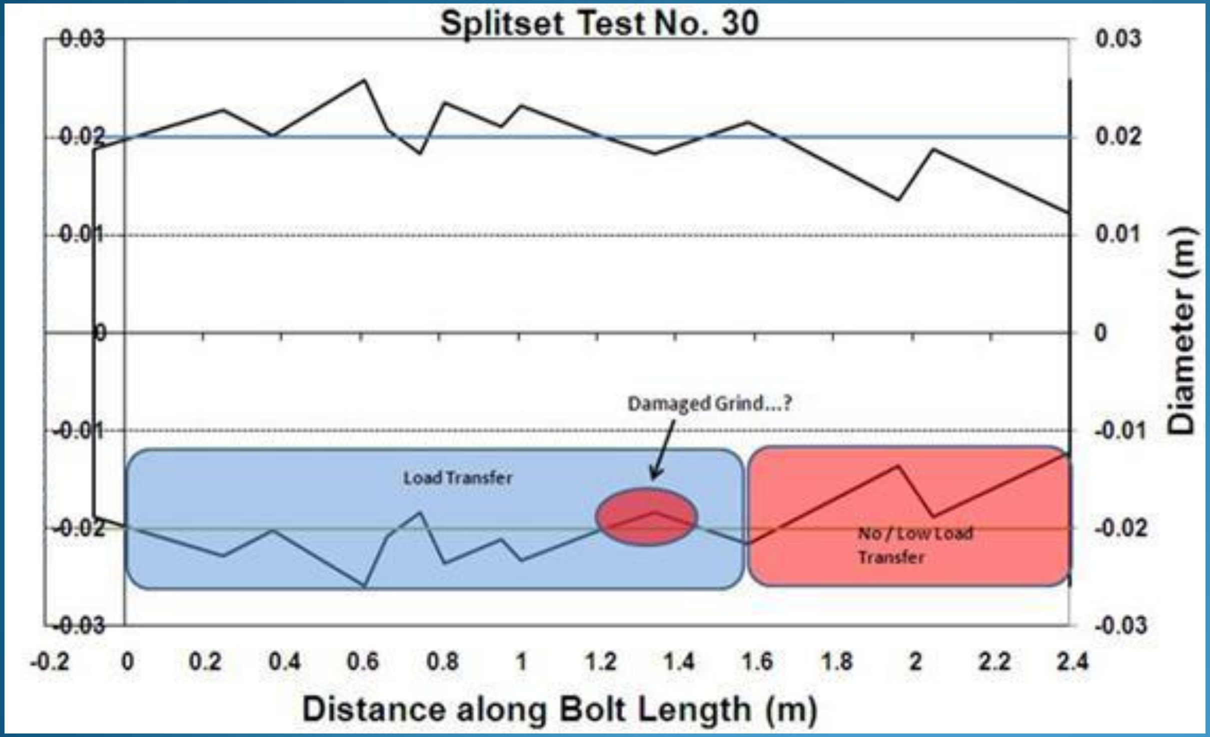
Integrity Testing Pty Ltd

GEOHART CONSULTANTS

Geotechnical *(Mining & Civil)*

Freyssinet

Results - Two dimensional plot with bolt diameter used as control against the length along bolt axis for the 2.4m long (damaged grind 1.2m) friction bolt, Test No.30.



The 2D mechanical admittance plot clearly shows mechanical admittance from the collar to about 1.2m and then no load transfer detected from about 1.7m to the toe of the friction stabiliser

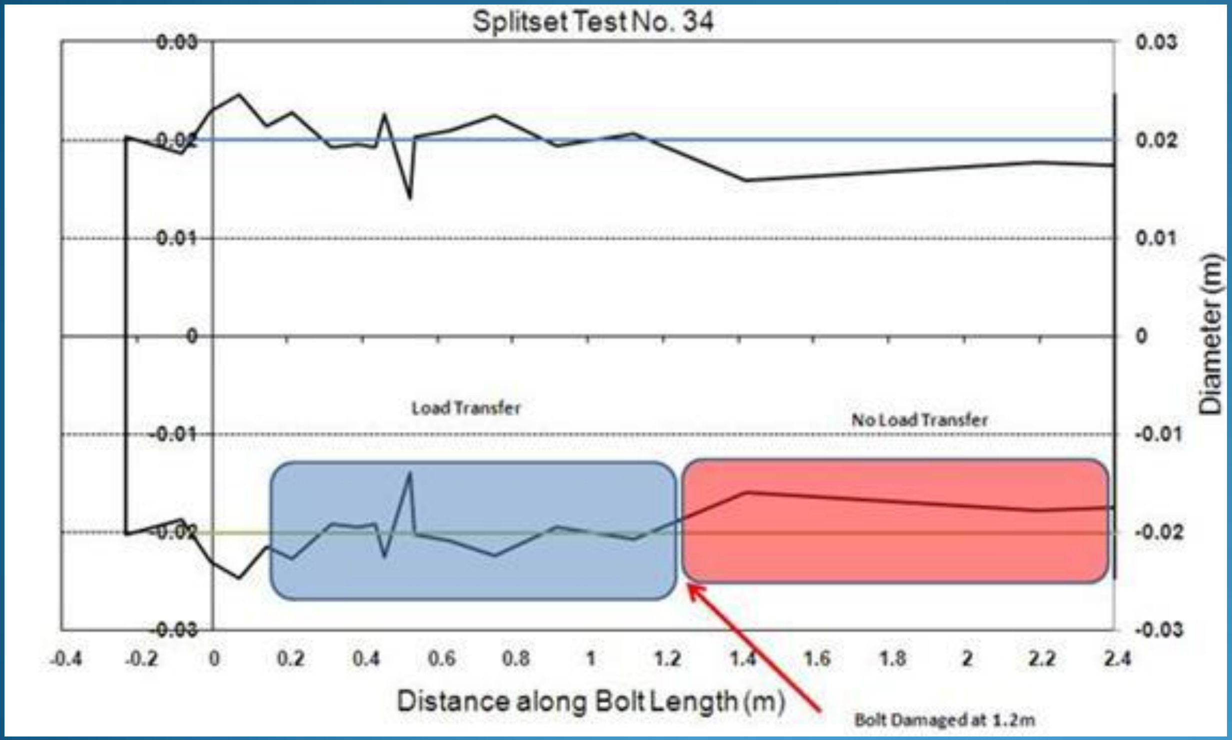
Integrity Testing Pty Ltd

GEOHART CONSULTANTS

Geotechnical *(Mining & Civil)*

Freyssinet

Results - Two dimensional plot with bolt diameter used as control against the length along bolt axis for the 2.4m long (damaged slot cuts 1.2m) friction bolt, Test No.34.



It was quite an interesting test. The friction bolt was damaged (i.e. cut slots) by George Fisher personnel at 1.2m from the collar. During the installation the friction bolt collapsed and was driven into itself. The test results or mechanical admittance plot shows that no load transfer occurred after 1.2m which agrees well with the actual bolt collapse

Integrity Testing Pty Ltd

GEOHART CONSULTANTS

Geotechnical *(Mining & Civil)*

Freyssinet

CASE STUDY

Bolts are 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

Category 1.	A perfect bolt in perfect rock conditions – in our opinion this will rarely occur
Category 2.	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.
Category 3.	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.
Category 4.	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

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.

Integrity Testing Pty Ltd

GEOHART CONSULTANTS

Geotechnical *(Mining & Civil)*

Freyssinet

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.

Integrity Testing Pty Ltd

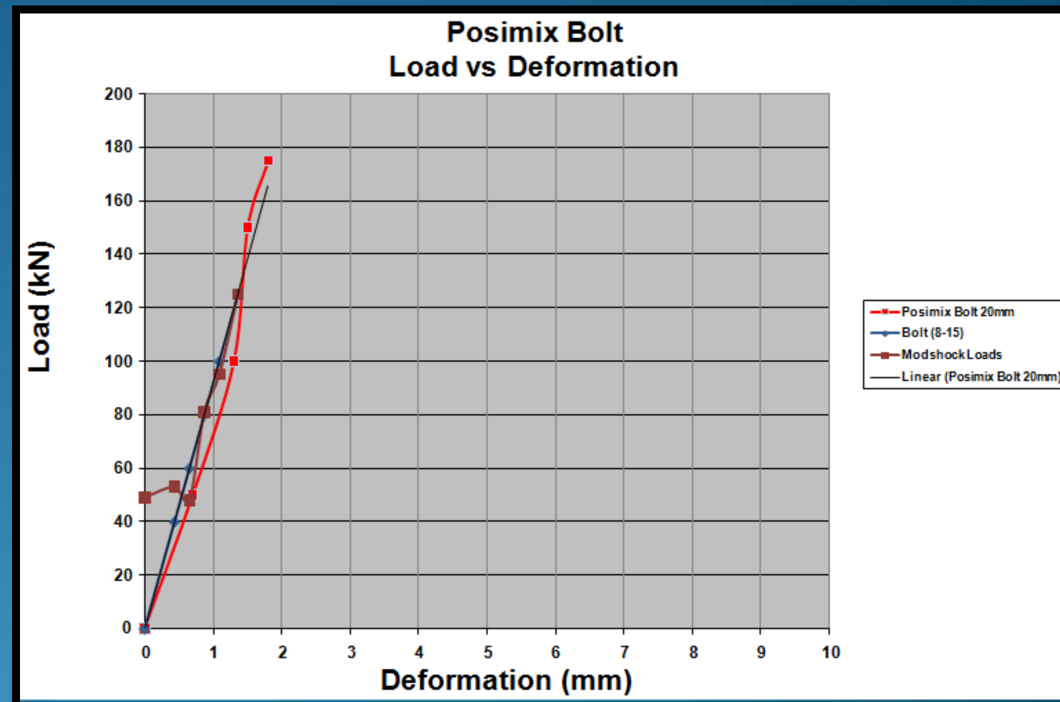
GEOHART CONSULTANTS

Geotechnical *(Mining & Civil)*

Freyssinet

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**

Integrity Testing Pty Ltd

GEOHART CONSULTANTS

Geotechnical *(Mining & Civil)*

Freyssinet

ACKNOWLEDGEMENTS

- George Fisher Mine Management for the opportunity to conduct the non-destructive rock reinforcement testing and publishing the results.
- A special thanks to Mr. Fred Harvey (Rock Mechanics Superintendent) for his arrangements.
- Mr. Graham Browne (Technical Rock Mechanics Officer) who was part of the testing team.

Thank You

Integrity Testing Pty Ltd

GEOHART CONSULTANTS

Geotechnical *(Mining & Civil)*

Freyssinet