

Non Destructive Integrity Testing Of Rock Reinforcement Elements in Australian Mines

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Geotechnical (*Mining & Civil*)



Presentation Layout

- Introduction
- Background to non-destructive testing
- Non-Destructive Testing Set-up and Method
- Test output
- Recent Findings
- Tests Results
- 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.

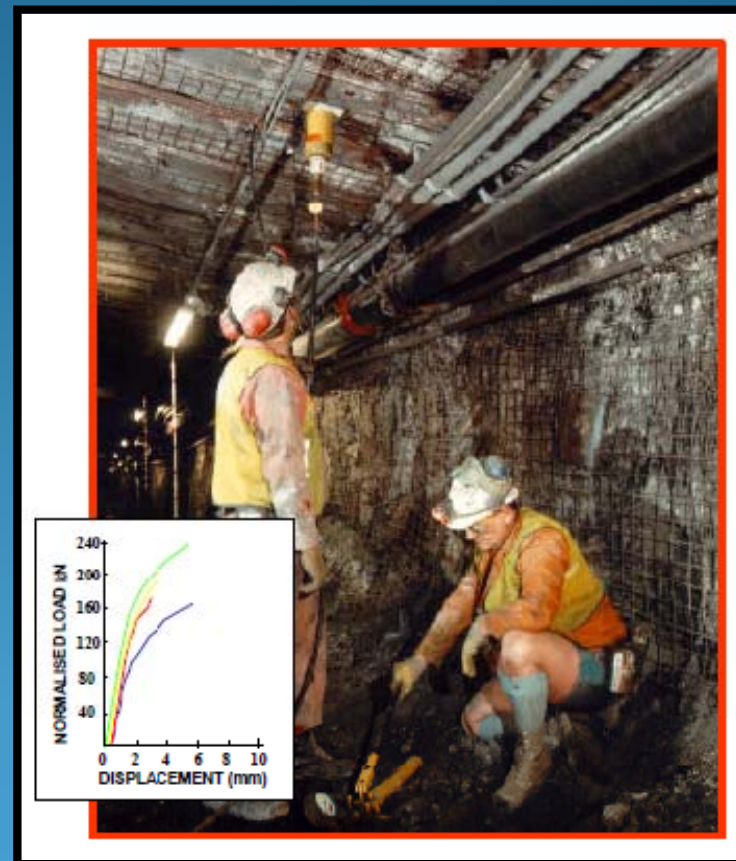
1990



INTRODUCTION (cont.)

2004

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INTRODUCTION (cont.)

2009

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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.



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 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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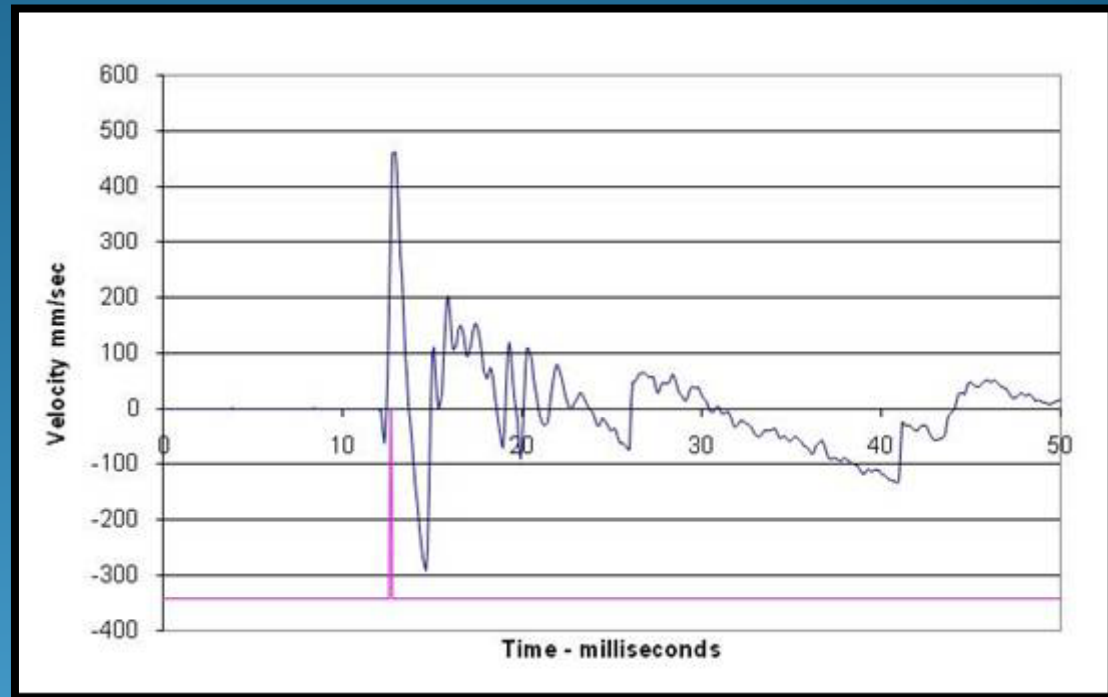
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TEST OUTPUT

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.



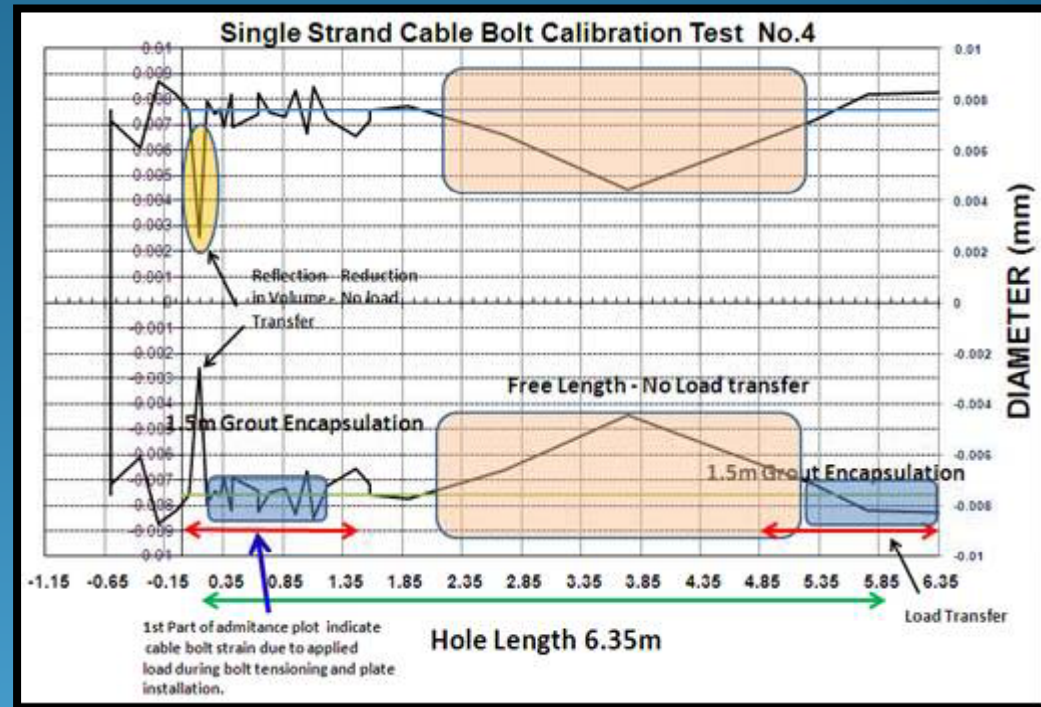
TEST OUTPUT

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.

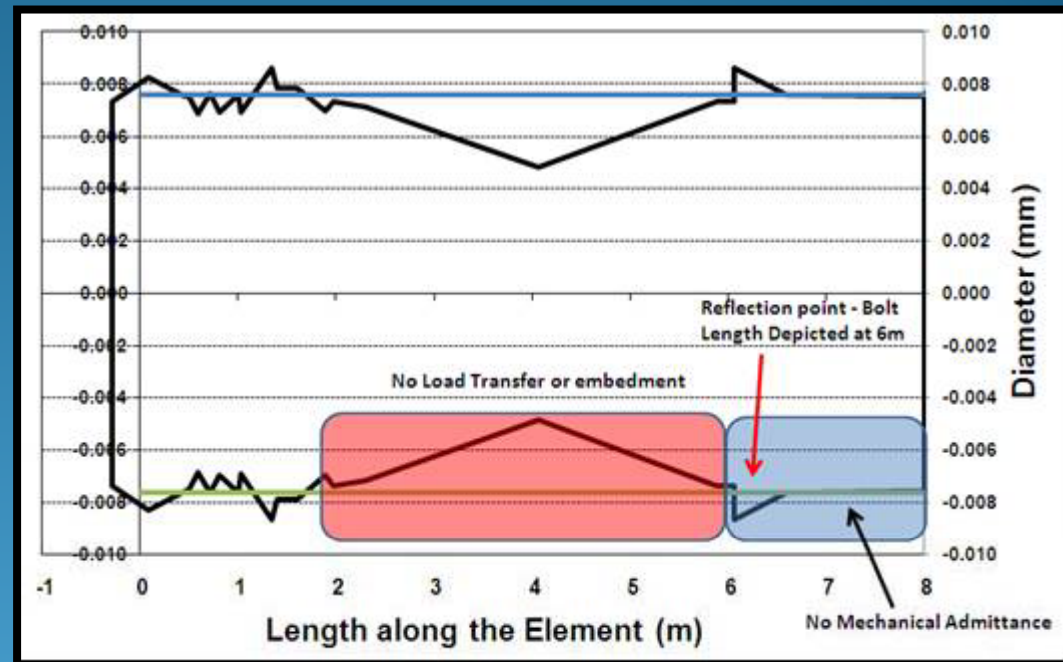


RECENT FINDINGS

Detection of poor grout injection and Rock Reinforcement Element Correct Length

In a recent test at the Fosterville Gold Mine cable bolt lengths were accurately depicted following confirmation from the mine. The test set-up incorporated 10m and 8m lengths as input parameters for the cable bolt testing. Most of the bolts were confirmed to be either 8m or 6m in length .

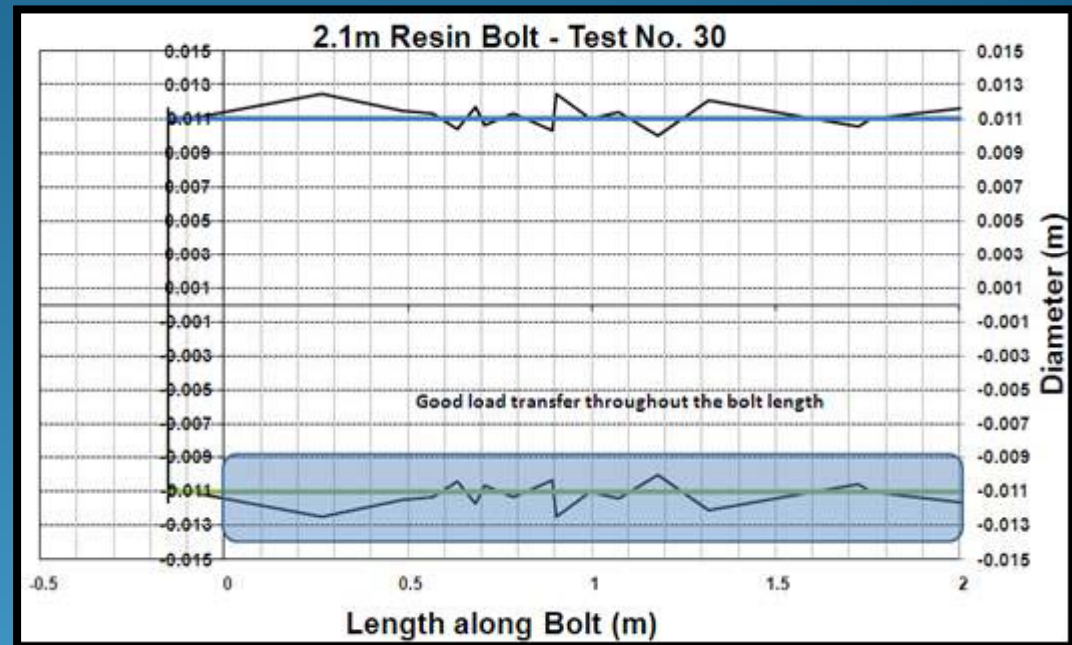
The graph clearly shows bolt length to be around 6m following test input parameter set to 8m. The bolt length was later confirmed by the mine to be a 6m twin strand cable bolt.



RECENT FINDINGS

Confirmation of good quality resin installation on solid rebars and Hi-Tens end anchored cable bolts

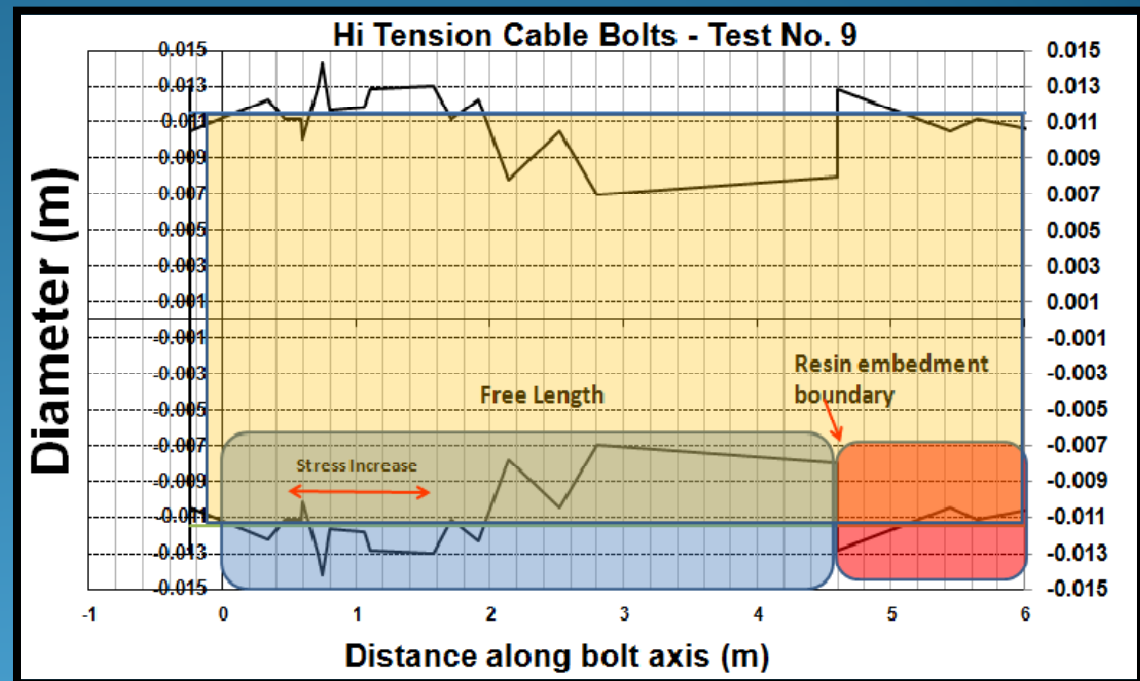
Test completed at Mandalong Coal Mine shows that the resin installation practices at Mandalong appear to be of good quality when interpreting the two dimensional graphs. The figure indicates good embedment (structural stiffness) along the length of the bolt.



RECENT FINDINGS

Confirmation of good quality resin installation on Hi-Tens end anchored cable bolts

The Hi-Tens cable bolts are installed using a 1200mm long slow set resin capsule at the back of the hole. The bolt is spun through the resin for about 14 seconds and hold for 120 seconds to activate the quick set resin. Tests conducted on the Hi-Tens tendon showed an interesting two dimensional graph where the resin installation is limited to the toe area of the bolt / hole as per design. A free anchor length of around 4.2m is maintained with the 2D plot showing either signs of stress increase or noise close to the collar.



TEST RESULTS

Non-destructive tests were carried out on a total of 227 bolts, comprising 89 rebar type bolts, 124 cable bolts and 14 splitsets were tested in four mines across Australia.

Mine	Stiff Splitsets	Splitsets or Friction Bolts	Resin Solid Rebar	Single Strand Cable Bolt	Multi Strand Cable Bolt	Hi Tensile Cable Bolt
A			14		31	
B	1	9	4	44	15	
C		4	34	7	8	
D			37			19

TEST RESULTS

Of the 227 bolts tested 36 were calibration bolts comprising of resin bolts, twin and single strand cable bolts and split sets. 191

Bolts were tested for defects:

- Insufficient grout / resin which affect the anchorage or anywhere along the length of the bolt;
- Bolts affected by corrosion displaying significant volume loss and reduced load transfer and/or bolts displaying low calculated stiffness 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

TEST RESULTS

- 70% of the 191 bolts tested were classified as serviceable
- 49% of the bolts tested had some kind of defect (i.e. suspect anchorage, low load transfer and/or volume reduction)
- 27% of the 191 bolts tested were classified as non-serviceable with the majority of the bolts showing a deficiency in end anchorage as per mine design and / or overstressed bolts due to excessive ground deformation.
- 2% of the 191 bolts tested have been classified as inconclusive. This relates to bolts being identified as short bolts or very poor anchorage but completely out of character for the type of bolt (under investigation)

Poor Signal	Inconclusive	1	2	3	4	Bolt Types
			14	14	9	Twin Strand Cable Bolts
2	4		7	27	2	Single Strand Cable Bolts
			11	8		Hi-Tens Cable Bolts
			8	41	34	Resin Bolts
1				3	6	Split sets
3	4	0	40	93	51	191
2	2	0	21	49	27	Percentages

TEST RESULTS

- *Comments from Fosterville Gold Mine:*

“At this stage the results of the Modshock system are a successful outcome for the quality of installation of the sites cable bolts. There are several issues to deal with, many of which have been removed through the employment of a Cabolter that is fit-for-purpose and applies best practice to the cablebolt installation system”.

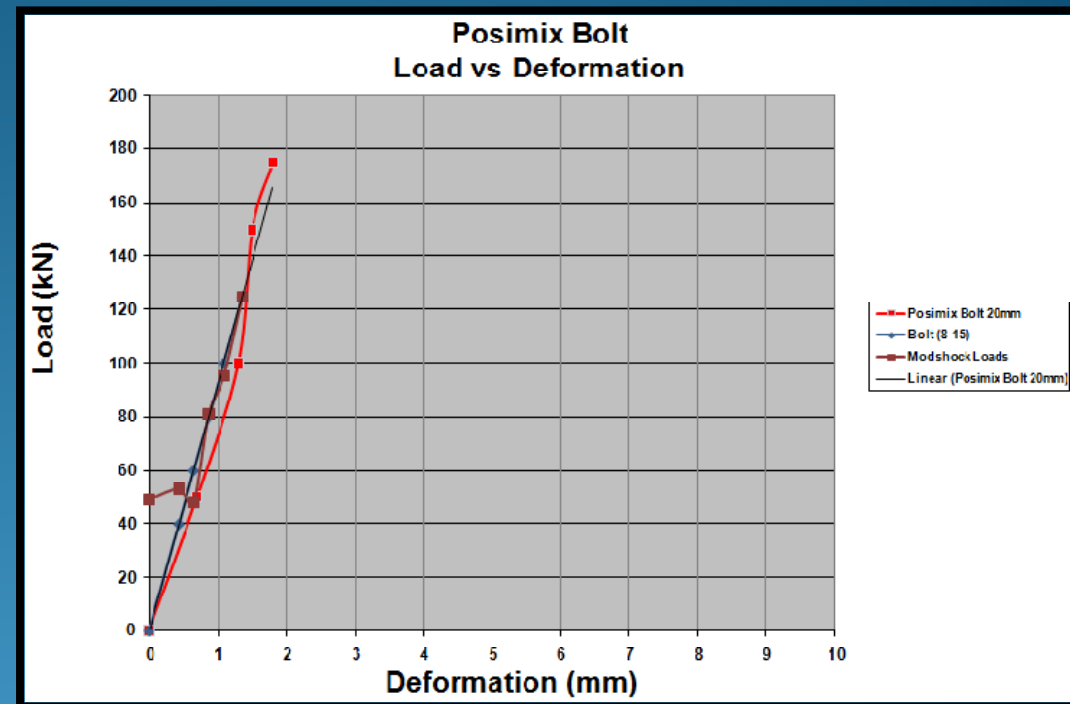
“The result of the testing is that we did get some useful results. Initially the results were interpreted without calibration or comparison data from other sites, as there was none available. Later testing at Sunrise Dam (Anglogold Ashanti) and Mandalong Coal Mine (Centennial) provided some perspective. “

CONCLUSIONS

- Ground support quality control has been a high priority for most mines but remained a high risk due to the uncertainty in the current bolt integrity testing procedure of pull testing.
- The use of non-destructive technology to test for defects (e.g. corrosion, necking) and lower quality installation techniques are showing an enormous opportunity in effectively manage this geotechnical risk.
- It has been found that verification of rock reinforcement designs (i.e. bolt lengths and full column resin/grout installations) and integrity confirmation are two of the biggest challenges for geotechnical engineers and mine management. However we are confident that this non-destructive integrity testing technique is a step towards reducing the uncertainty in quality and integrity assessment of rock reinforcement systems.

FUTURE WORK

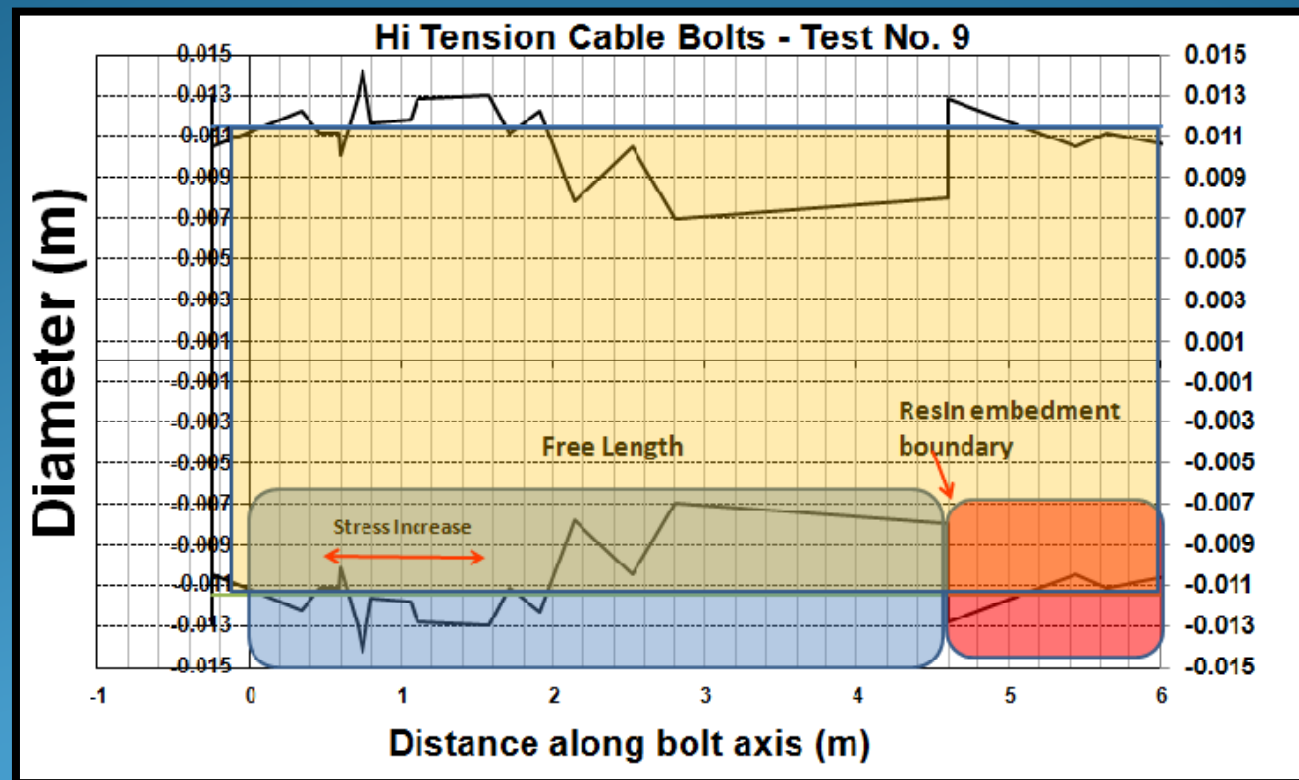
We acknowledge that we need to conduct the following work to increase confidence in other data interpretation:



- Calibration testing to confirm the elastic load increase in tendons and solid rebars as referred to in this paper and

FUTURE WORK

- Confirmation of two dimensional graph amplitude variance and descriptive analysis.



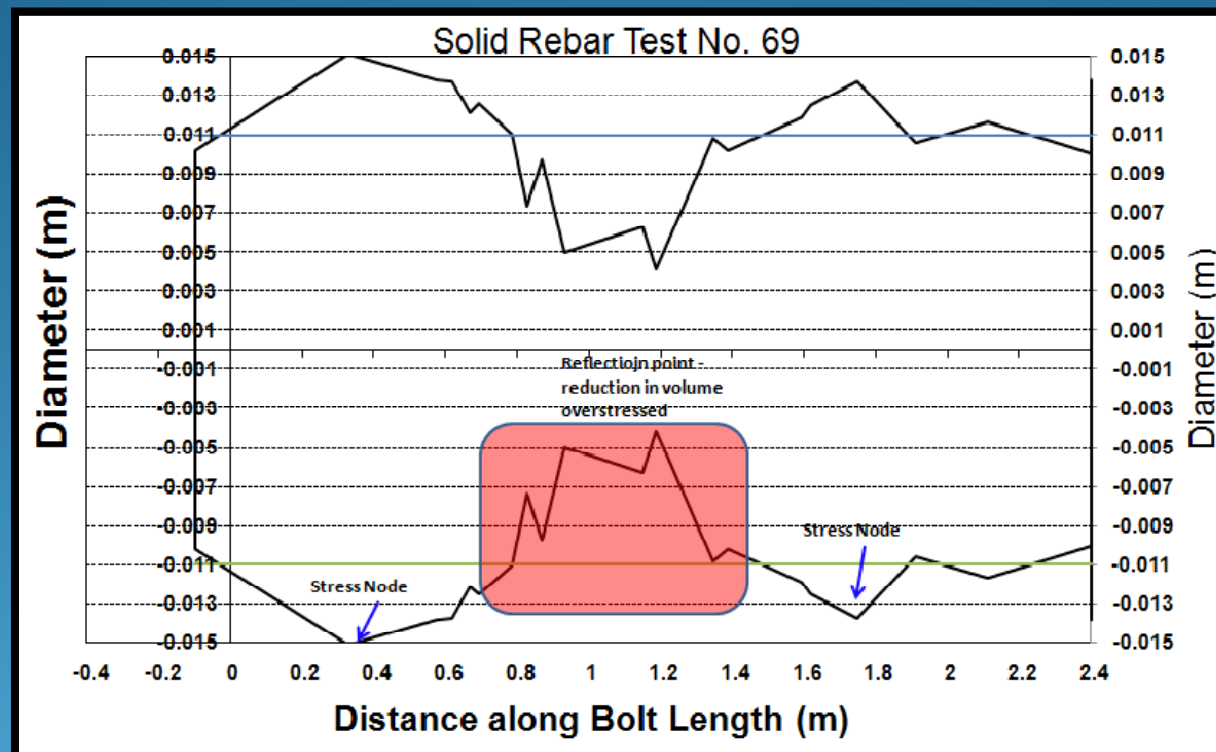
FUTURE WORK AND QUESTIONS

The areas requiring further attention and investigation with the method include:

- Signal/head fixture → variability of plate/barrel stiffness and effects on results
- Issues with result in first 1.5m of the bolt → stress on bolt from tensioning or noise? Much higher resolution
- Error bars → is there a confidence range (possibly a variable one depending on amplitude) in which results in this range are OK?
- Grout strength → how does this affect the results? – It certainly does effect the results as it shows low structural stiffness
- Ground structure→ how do these affect the results? – Any weaker or lower density material is detected hence an alarm to zone in on particular area
- What *does* corrosion look like?

FUTURE WORK AND QUESTIONS

What *does* corrosion look like?



ACKNOWLEDGEMENTS

- Fosterville Gold Mine – Northgate Minerals
- Sunrise Dam Gold Mine – AngloGold Ashanti
- Mandalong Coal - Centennial

Questions...?