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Evaluating methods of underground short encapsulation pull testing in Australian coal mines

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EVALUATING METHODS OF UNDERGROUND SHORT ENCAPSULATION PULL TESTING IN AUSTRALIAN COAL MINES

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ABSTRACT: In May 2012, an Australian Coal Association Research Program (ACARP) funded project C21011 commenced to develop coal industry standard test methods for assessing resin chemical anchors. The project was run by the University of Wollongong with assistance from Australia's two resin anchor manufacturers, J-Lok and Orica. A program of field and laboratory studies was undertaken to examine various factors influencing effective the load transfer mechanism between the bolt/resin and rock to ensure test methods represented field performance.

This paper discusses the field component of the research project. A series of Short Encapsulation Pull Tests (SEPT) were carried out in three mines with different geological conditions to determine the most representative and practical method of SEPT. Additional field work included installation of bolts into threaded steel tubes for subsequent laboratory evaluation. Factors of importance considered to affect bolt installation and the subsequent SEPT representing the fully encapsulated bolt performance included; borehole diameter, resin annulus thickness, installation time (including bolt spin to the back and "spin at back"), the effect of gloving and its impact on installation quality of the bolt and load transfer variation along the length of the installed bolt.

INTRODUCTION

The resin bond between rock bolt and the strata is one of the critical elements of a roof bolting system, yet the Australian coal industry does not have an agreed standard for bolting system evaluation. Australia continues to rely on other country's' standards, notably British, South African, and USA to evaluate its bolting systems even though material components are significantly different to those other countries. The Australian usage of bolting systems is much more homogeneous with similar diameter bolts and with little diversity in the use of resin until now. In light of the recent increases in various resin types in Australian coal mines, there is a need for setting up a practical method of testing, by the end users

Mark, *et al.,* (2002) described the US study by NIOSH aimed at developing a US standard Short Encapsulation Pull Tests (SEPT) method. The non-reamed and reamed hole methods described by Mark *et al.,* (2002) are illustrated in Figure 1. These methods form the basis of the Australian study using M24 threaded rebar bolts and oil based catalyst resin most commonly used by the Australian industry.

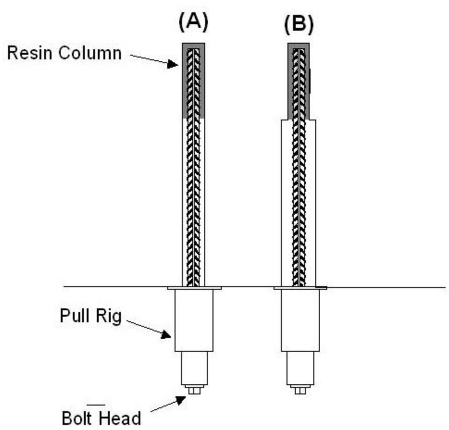

Figure 1 - The Short Encapsulation Pull Test. (A) Normal hole; (B) Reamed hole (Mark, *et al.,* 2002)

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The Australian study used the most common 21.7 mm core diameter, M24 threaded X-grade bolt as illustrated in Figure 2. The most common oil based catalyst fast set polyester resin was used, containing a 5-7% catalyst component.

Hillyer(2012) highlighted that Australia's M24 bolts fully encapsulated in 28 mm diameter threaded pipes gave a variable bond strength performance along their length due to variable mixing of the resin and gloving from the plastic capsule film. The new ACARP study considered that pull testing the very top 200 – 300 mm of encapsulated bolt may not be representative of the entire fully encapsulated bolt, and that changes in the SEPT method should be explored.

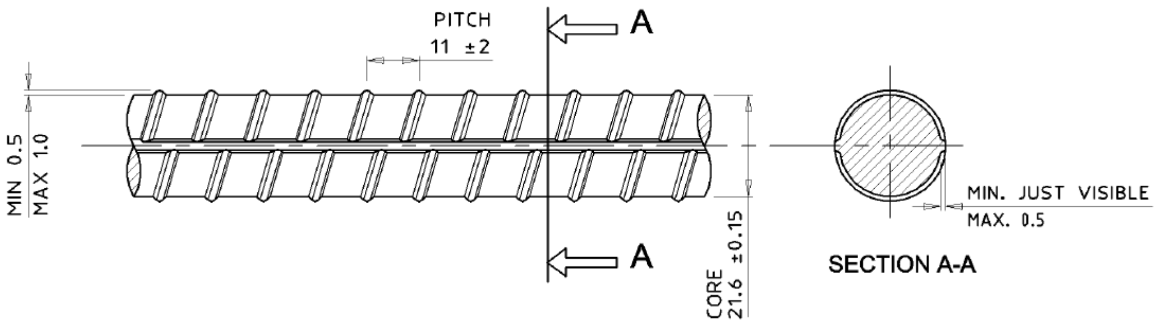


Figure 2 - Australia's most common profile X grade bolt

Testing was carried out at three different mine sites. Baal Bone Colliery mines the Lithgow seam and roof bolts were anchored into a moderate strength mudstone. Tahmoor Colliery mines the Bulli seam and roof bolts were anchored into a strong siltstone, whilst NRE Colliery, Russell Vale, the Wongawilli seam with roof bolts being anchored through a weak coal roof. All testing was done in a selected outbye are with no significant fracturing of the strata. The installation equipment used at all three sites were Alminco Goafer hand-held compressed air rotary bolters operating at 600 – 700 rpm.

The underground SEPT were carried out by researchers from the University of Wollongong alongside Jennmar mine service technicians who are experienced operators of both the hand-held bolting installation and hydraulic pull testing equipment.

DIFFERENT SEPT METHODS TESTED

Drill bits used at the sites were twin-wing rotary water flush 'angle' bits. The first test site included 28 mm and 27 mm diameter drill bits for comparison, whilst the remaining study sites used 27 mm bits only. Hillyer *et al.* (2013) identified the variability in load transfer from mixing. A SEPT only involves mixing through 200 – 300 mm of resin capsule which would be significantly different to mixing through a full length resin capsule typically 1000 – 1400 mm long. The underground tests included the following variable mix times for investigation;

1. The manufacturers recommended mix time of 10 seconds. Taking 5 s to spin through the capsule and 5 s when the bolt was at the back of the hole
2. Under-mixing with a total of 5 seconds. Taking 3 s to spin through the capsule and 2 seconds at the back of the hole
3. Over mixing with a total over 30 s

The reamed and non-reamed SEPT was used at Baal Bone and NRE Russel Vale test sites due to being weaker types of rock. The reamed test was used exclusively at Tahmoor mine with both 200 mm and 300 mm bond length due to the known stronger rock.

The issue of gloving has been identified by many previous studies, and has been found to be most likely at the top of the bolt. The SEPT only tests the top of the bolt and is therefore more likely to be prone to gloving reducing the bond strength results. It was decided to trial 50 mm of overdrill to provide a space for the plastic film to accumulate and not interfere with the bolt/resin/rock interface. This overdrill method was trialed at all test sites and is illustrated in Figure 3.

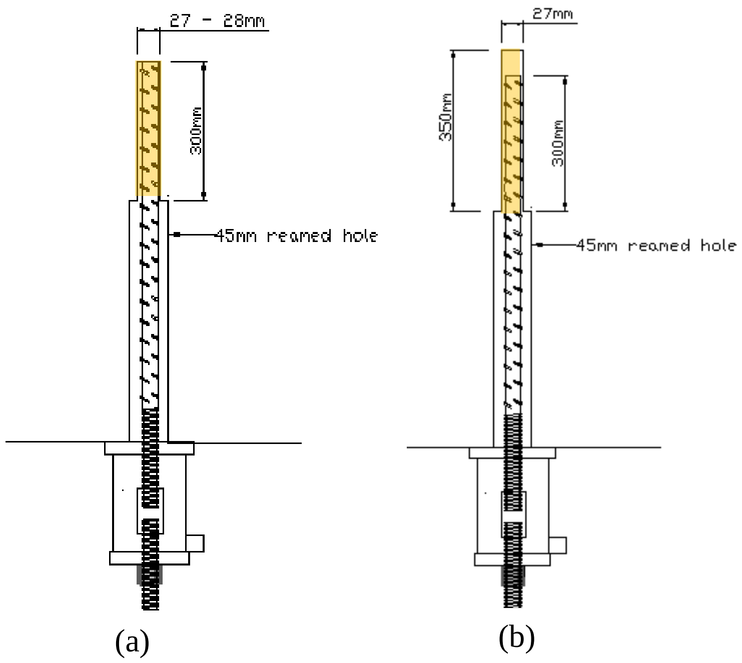


Figure 3 - (a) Reamed standard and (b) Reamed overdrill

RESULTS

Baal Bone Colliery

The first SEPT field investigation was carried out at Glencore's Baal Bone Colliery. The mine ceased production in 2011 but has been kept open as a training facility for Glencore employees.. A total of 24 short encapsulation bolts were installed at Baal Bone. All bolts were installed in the Triassic mudstone/shale immediate formation above the Lithgow seam, with known typical strength of 35 MPa.

Table 1 shows the summary of retrieved data of the bolt pull testing with subsequent analysis. The bond strength (kN/mm) was determined as the peak (maximum) pull load divided by the encapsulation length. Figure 4 shows the average pull test load-displacement profiles of the different set of test methods.

Bolts 5, 6, 7 and 8 installed in smaller diameter holes of 27 mm achieved better load transfer capacity than the bolts installed in 28 mm diameter boreholes (1, 2, 3 and 4). It is envisaged that the top 200 mm bond strength of most bolts, was significantly reduced, because of the accumulation of the capsule plastic film remnants in the over-drilled length. Thus the 50 mm over-drilled space allows resin skin shredding to accumulate in the over drill space above the bolt end and away from the area between the bolt and the reamed section of the borehole. Consequently, the results showed an extremely significant improvement. Thus, it is reasonable to conclude that the current short encapsulation pull test method used to study bond strength appears to demonstrate the effectiveness of hole over drill in Australian mines.

The non-reamed installations used a borehole micrometer and encapsulation chart to calculate the length of capsule required to target 300 mm of bond length. Table 1 shows that the bond lengths achieved varied between 368 mm and 419 mm which demonstrate the difficulty of the method with variables of capsule preparation and borehole micrometer error a significant problem.

In summary, it can be inferred from the pull testing at Baal Bone that:

1. Bolt installation time of around 10 s constitutes an acceptable time for effective bolt installation as is normally recommended for use with Minova/Orica fast setting resin of 14 s,
2. The results of the over spinning at back was inconclusive, because the spin times to shear the pin were too extreme in the 300 mm limited bolt encapsulation length,

3. The use of 300 mm long encapsulation length may be the maximum acceptable length for pull testing, but this depends on the type of the rock formation, which has some bearing on load transfer capability of the installation. This finding is in agreement with the study carried out by Willkinson and Canbulat (2005),
4. In-line reamer drill rod saved time for drilling reamed holes and provided repeatable accurate bond lengths.
5. Hole over drilling contributed to increased load transfer capacity of the installed bolt and thus became the accumulation zone for the gloving material.

Table 1 - Analysed data from the short encapsulation pull tests-Baal Bone Mine

Bolt No.	Peak Load (kN)	Bond Strength (kN/mm)	Displacement at Peak (mm)	Spin to Back (sec)	Spin at Back (sec)	Total Spin Time (sec)	Bond Length (mm)	Average Hole Dia. (mm)	Borehole Type
1	117.7	0.39	4.7	3	7	10	300	28	reamed
2	98.1	0.33	5.9	3	7	10	300	28	reamed
3	117.7	0.39	10.0	3	7	10	300	28	reamed
4	107.9	0.36	1.3	3	7	10	300	28	reamed
5	137.3	0.46	3.5	5	5	10	300	27	reamed
6	176.6	0.59	1.6	5	5	10	300	27	reamed
7	166.8	0.56	2.2	5	5	10	300	27	reamed
8	147.2	0.49	2.6	5	5	10	300	27	reamed
9	147.2	0.49	1.8	3	2	5	300	27	reamed
10	137.3	0.46	1.8	3	2	5	300	27	reamed
11	157.0	0.52	2.0	3	2	5	300	27	reamed
12	137.3	0.46	4.0	3	2	5	300	27	reamed
13	94.2	0.31	3.3	3	22	25 (NB)	300	27	reamed
14	95.2	0.32	3.2	3	31	34 (NB)	300	27	reamed
15	73.6	0.25	5.5	3	47	50 (NB)	300	27	reamed
16	29.4	0.10	3.5	3	39	42 (NB)	300	27	reamed
17	215.8	0.59	2.4	5	5	10	368	28	NOT reamed
18	215.8	0.56	4.4	5	5	10	385	28	NOT reamed
19	215.8	0.54	2.7	5	5	10	402	28	NOT reamed
20	215.8	0.52	1.7	5	5	10	419	28	NOT reamed
21	215.8	0.72	4.6	5	5	10	300	27	reamed + 50 mm OD
22	206.0	0.69	2.8	5	5	10	300	27	reamed + 50 mm OD
23	157.0	0.52	2.5	5	5	10	300	27	reamed + 50 mm OD
24	215.8	0.72	2.3	5	5	10	300	27	reamed + 50 mm OD

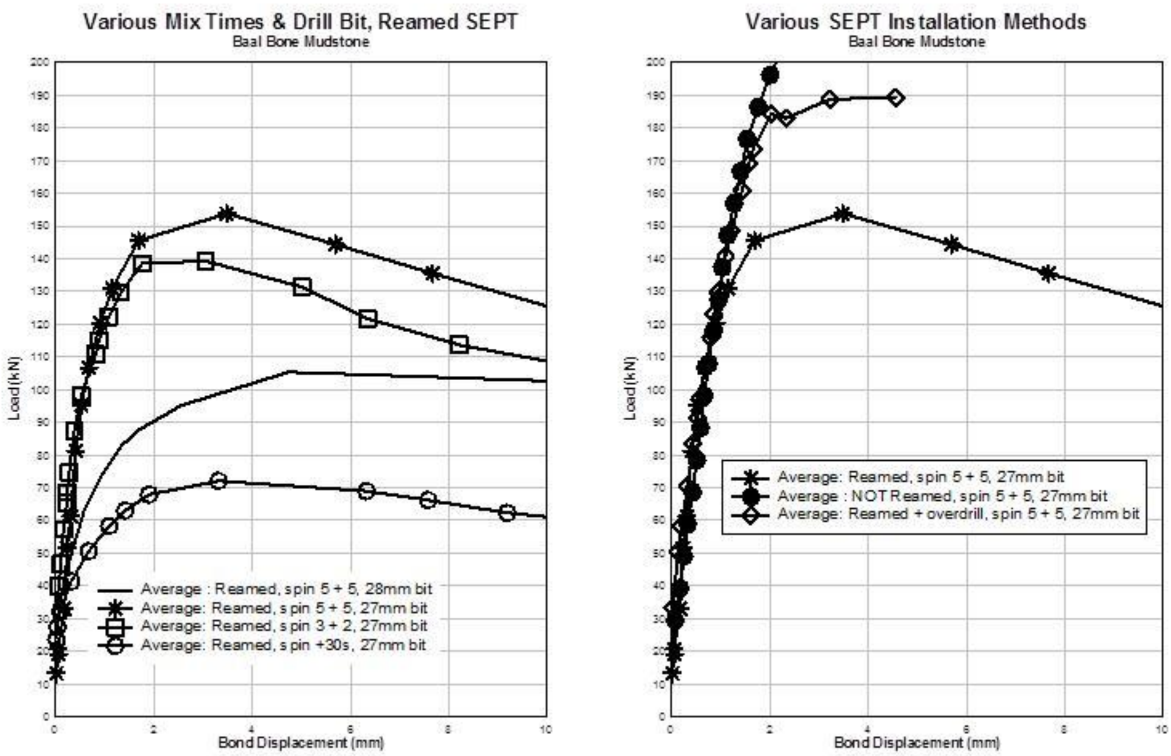
- *Bolt: JBX, Core diameter: 21.7 mm, Length: 1200 mm, Installed horizon: 1100 mm; Resin: Orica, fast-setting, RA33025F.*
- *Un-reamed holes encapsulation length was achieved by wrapping tape around the end of the first 300 mm length of the bolt.*
- *Bond strength is defined as the maximum pull load/encapsulation length.*

Tahmoor Colliery

The next round of pull testing was carried out at Glencore's Tahmoor Colliery in late November 2012. The Bulli seam roof is relatively stronger than the Lithgow measures of Baal Bone mine and comprises mudstone, shale and sandstone. Therefore, the mine roof at the test site can be described as moderately competent. Similar to Baal Bone, a total of 24 bolts were installed in intersection 5/1 near the pit bottom. The process of drilling and installation of 24 rock bolts as well as the equipment used was similar to the bolt installation operation at Baal Bone mine.

Two encapsulation lengths of 200 mm and 300 mm were trialled at Tahmoor, with and without the additional 50 mm of over drilling. The installation time of the bolts was mostly in accordance with the normal standard time of 10 s, however, there were some variations, mostly at lower installation times as shown in Table 2.

Table 2 highlights the summary of test results and analysis. The 200 mm long short encapsulation pull tests for the first eight bolts (1- 8) showed a variation in bond strength between the standard hole length and the 50 mm over-drilled holes. The over-drilled holes pull test values were, in most cases, higher than the standard installations. The influence of over drilling is also evident with bolts installed at short installation times in bolts 22 and 24. Similar to the Baal Bone Mine study, the over-drilled holes generally showed a significant improvement in the load bearing capacity of the bolts.



(a) (b)

Figure 4 - Baal Bone Colliery: Variation in load transfer capacity by SEPT method

Table 2 - Analysed data from the short encapsulation pull tests- Tahmoor Mine

Bolt No.	Peak Load (kN)	Bond Strength (kN/mm)	Displacement at Peak (mm)	Spin to Back (sec)	Spin at Back (sec)	Total Spin Time (sec)	Bond Length (mm)	Borehole Type
1	98.1	0.49	2.6	5	5	10	200	reamed
2	127.5	0.64	4.3	5	5	10	200	reamed
3	127.5	0.64	2.3	5	5	10	200	reamed
4	127.5	0.64	3.9	5	5	10	200	reamed
5	166.8	0.83	2.6	5	5	10	200	reamed + 50 mm OD
6	137.3	0.69	2.4	5	5	10	200	reamed + 50 mm OD
7	147.2	0.74	3.4	5	5	10	200	reamed + 50 mm OD
8	107.9	0.54	1.8	5	5	10	200	reamed + 50 mm OD
9	235.4	Long encapsulation	4.6	5	5	10	300	reamed
10	201.1	0.67	6.3	5	5	10	300	reamed
11	235.4	Long encapsulation	3.2	5	5	10	300	reamed
12	235.4	Long encapsulation	4.4	5	5	10	300	reamed
13	186.4	0.62	3.2	5	5	10	300	reamed + 50 mm OD
14	225.6	Long encapsulation	4.0	5	5	10	300	reamed + 50 mm OD
15	225.6	0.75	6.5	5	5	10	300	reamed + 50 mm OD
16	215.8	0.72	3.3	5	5	10	300	reamed + 50 mm OD
17	78.5	0.39	1.3	3	2	5	200	reamed
18	63.8	0.32	5.3	3	2	5	200	reamed
19	98.1	0.49	2.0	3	2	5	200	reamed
20	34.3	0.17	2.2	3	2	5	200	reamed
21	107.9	0.54	11.7	3	2	5	200	reamed + 50 mm OD
22	137.3	0.69	2.4	3	2	5	200	reamed + 50 mm OD
23	98.1	0.49	1.5	3	2	5	200	reamed + 50 mm OD
24	147.2	0.74	1.9	3	2	5	200	reamed + 50 mm OD

NB: OD – over drill. All encapsulated holes diameter: 27mm. All holes reamed. Bond strength (kN/mm) is the peak (maximum) pull load divided by the encapsulation length

Within the over-drilled bolts with 200 encapsulation length, bolt 5 had the highest bond strength at around 167 kN, with mixing time of 5 s "spin to back" plus 5 s "spin at back".

As expected, the pull test results for 300 mm long encapsulation length yielded significantly stronger bond strength, which, at times, exceeded the 22 – 24 t yield strength of the bolt.

It is not possible to draw any realistic and comparative conclusion between the standard 300 mm long encapsulation with and without over drilling (bolts 9 to 16) as pull test loads were close to bolt yield strength. However, the narrow and higher margins in pull loads were evident in over-drilled hole bolt installations, hence it is reasonable to assume that the over drill installation pull load values were better than the standard bolt installations. The profiles of the load-displacement graphs are shown in Figure 5.

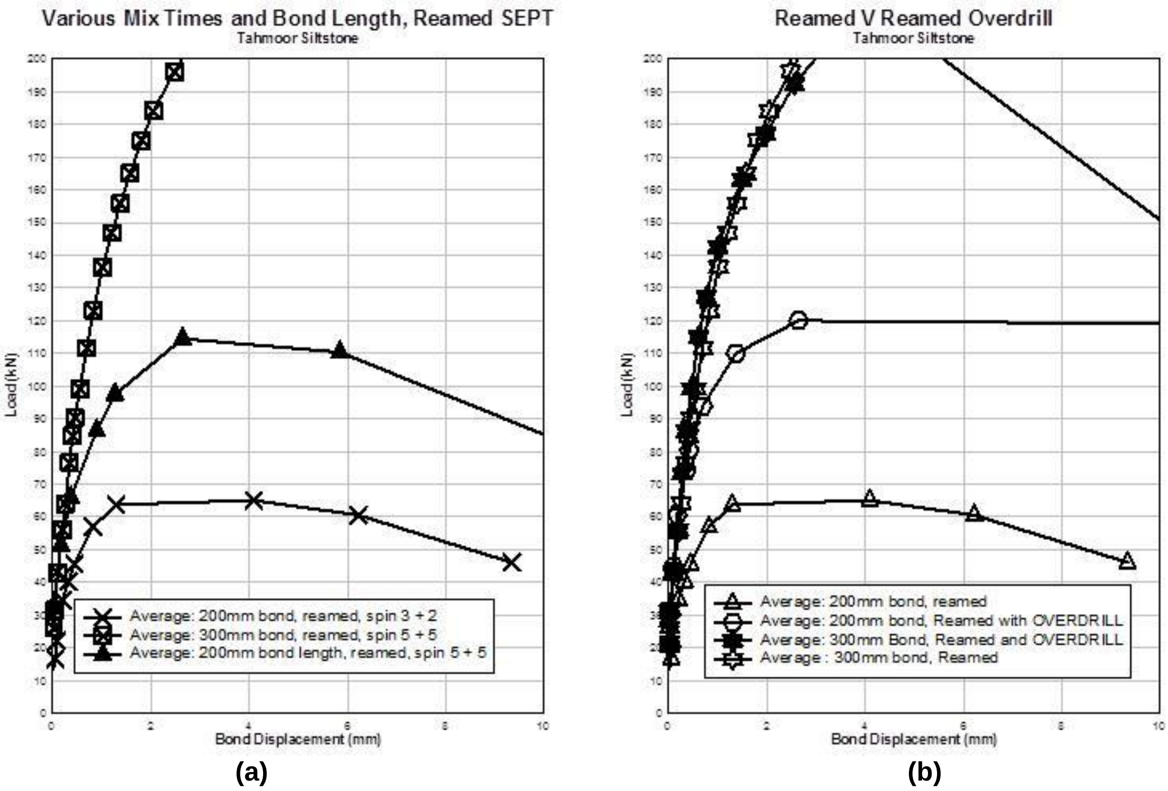


Figure 5 - Tahmoor (a) 200 mm V 300 mm Bond Length, (b) Reamed V Reamed Over-drill

With regard to short installation times, it is clear that shorter installation spin times of less than 10 s were inadequate for proper resin mixing to allow effective anchorage and hence a relatively lower peak pull load strength. Again over drilling appears to yield relatively superior bond strength.

Thus, it can be inferred from the tests carried out at Tahmoor Colliery that:

- bolts installed in over-drilled holes had superior load transfer capacity
- as expected, the 300 mm encapsulation length yielded greater load transfer capacity (higher pull force values) leading to yield strength, and
- shorter mixing time of half the recommended 10 sec was counter-productive for an effective load transfer mechanism. Prolonged "spin time at back" and shorter "spin time to back" is also counter-productive.

NRE Colliery, Russell Vale

The third and final round of field tests was carried out in mid-December 2012 at NRE Rusell Vale Colliery within the Wongawilli Seam. The test site was located in C heading, between CT20 and 21 of the Wongawilli Seam East main headings. The selected stratification above the working part of the Wongawilli Seam was a soft formation of mainly coal layers and clay bands.

In a similar manner to the previous field studies, an even and flat roof area was selected at the CT20 intersection for bolt installation. A total of 16 bolts, 1200 mm long, were installed in 1100 mm long holes using a handheld and compressed air operated Alminco Gopher drill. Table 3 shows the details of pull testing results.

- Encapsulation length of the first 12 holes were constant at 300 mm and the encapsulation lengths of holes 13 to 16 holes were variable as indicated in Table 3.
- Bolts 1 to 4 were installed in 50 mm long over-drilled holes with a reamed 200 mm bottom section. The installation time was consistent at standard time of ten seconds (5 s "spin to back" and 5 s "spin at back").
- Bolts in holes 9 to 12 were installed at the total spin time of five seconds (2 s "spin to back and 3 s "spin at back").
- In the unreamed holes13-16, the desired anchorage lengths of holes 13 to 16 were accomplished by wrapping an insulation tape of sufficient thickness around the bolt to the determined length, thus preventing the resin from spreading down the length of the bolt.

Table 3 - Analysed data from the short encapsulation pull test-NRE No.1

Bolt No.	Peak Load (kN)	Bond Strength (kN/mm)	Displacement at Peak (mm)	Spin to Back (sec)	Spin at Back (sec)	Total Spin Time (sec)	Bond Length (mm)	Average Hole Dia. (mm)	Borehole Type
1	215.8	0.72	2.8	5	5	10	300	27	reamed + 50 mm OD
2	137.3	0.46	2.1	5	5	10	300	27	reamed + 50 mm OD
3	147.2	0.49	3.4	5	5	10	300	27	reamed + 50 mm OD
4	137.3	0.46	2.9	5	5	10	300	27	reamed + 50 mm OD
5	73.6	0.25	2.7	5	5	10	300	27	reamed
6	127.5	0.43	3.9	5	5	10	300	27	reamed
7	107.9	0.36	1.5	5	5	10	300	27	reamed
8	78.5	0.26	1.0	5	5	10	300	27	reamed
9	117.7	0.39	2.6	2	3	5	300	27	reamed
10	157.0	0.52	7.0	2	3	5	300	27	reamed
11	127.5	0.43	5.0	2	3	5	300	27	reamed
12	103.0	0.34	6.0	2	3	5	300	27	reamed
13	196.2	0.61	3.6	3	7	10	320	28	NOT reamed
14	157.0	0.56	2.7	3	7	10	280	28	NOT reamed
15	98.1	0.34	2.5	3	7	10	290	28	NOT reamed
16	157.0	0.68	1.4	3	7	10	230	28	NOT reamed

NB: BH encapsulated length diameter 27 mm, using twin-wing bit
Holes 1-12 were reamed using a 45 mm diameter in-line reamer

With regard to the non-reamed holes, using the average diameter of holes the length of resin capsules were calculated and resin capsules were cut and re-sealed accordingly. The length of the resin capsules was 250 mm for bolt installation in 300 mm anchorage.

Table 3 shows the current 300 mm short encapsulation pull test for the first 12 rock bolts. As can be seen the un-reamed holes with variable encapsulation length have a better load bearing capacity of up to 196 kN in comparison with the performance of reamed holes with 300 mm encapsulation lengths. Figure 6 shows the load displacement graphs of all the bolts. It is clear that the performance of the first four bolts installed in over-drilled holes was better than the bolts installed with the standard methods without over drilling.

The following were inferred from the pull tests at NRE Russel Vale installations in the Wongawilli formation:

1. Bolts installed in the over-drilled holes (bolts 1-4) had relatively higher pull loads than the ones installed in holes 5 and 8 without over drilling.
2. The pull load of bolts installed at shorter installation spin time was, in general greater that the standard 10 s time.

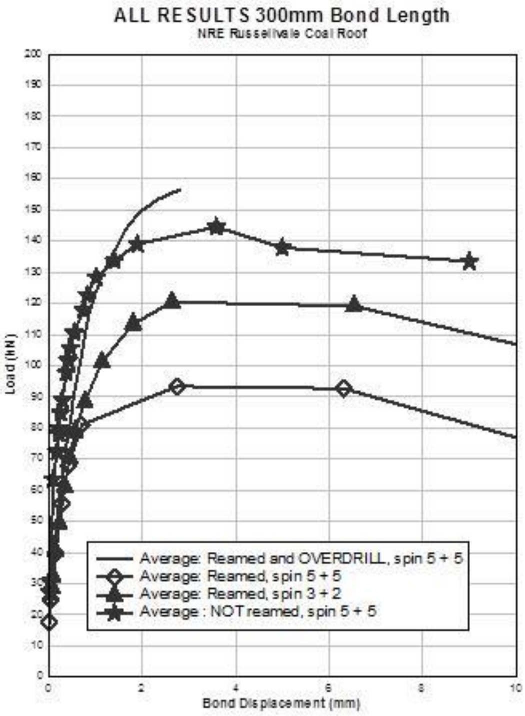


Figure 6 - All results NRE Colliery, Russell Vale

CONCLUSIONS AND RECOMMENDATIONS

Given the limited number of bolts installed at three sites of varying geological formations, it is clear that over drilling of the bolts by 50 mm has led to load transfer capacity improvement. This increase in bolt resin rock bonding can be attributed to the resin capsule film being pushed upwards and accumulating in the over drill space above the bolt end. The removal of the film from the main body of the resin mixture has permitted increases in bonding strength between the bolt, resin and rock. This finding is being further analysed in the ACARP Project.

The following conclusions were inferred from the field SEPT study:

- Bolt installation time of approximately 10 s constitutes an acceptable time for effective bolt installation as is normally recommended for use with Minova/Orica fast setting resin of 14 s,
- The results of the over spinning at back was inconclusive because of the limited bolt encapsulation length
- The use of 300 mm long encapsulation length may be the maximum acceptable length for pull testing. This may also depend on the type of the rock formation, which has some bearing on load transfer capability of the installation. This finding is in agreement with the study carried out by Willkinson and Canbulat (2005).
- Over drilling contributed to increased load transfer capacity of the installed bolts and thus became the accumulation zone for the gloving material.
- Non-reamed methods are not repeatable and accurate due to the errors in borehole measurement and capsule preparation.

ACKNOWLEDGEMENTS

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