

# 12th CONFERENCE ON GROUND CONTROL IN MINING

## FLEXIBOLT Flexible Roof Bolts: A New Concept for Strata Control

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### ABSTRACT

A high strength steel strand bolt has been developed by Barrett, Fuller & Partners as a replacement for conventional rigid bars for primary roof support in coal mines. It is based on a 23mm diameter multiwire steel strand with a tensile strength of 55 to 60 tonnes. The paper summarizes the development of FLEXIBOLT flexible roof bolts, their reinforcement performance and their potential to provide operators, currently reliant on medium to high density roof bolting systems, with a viable, low density roof bolting system offering high roof reinforcement capacity along with the option of installing bolts longer than headroom, in a single pass at the face.

### INTRODUCTION

For some 20 years, it has been recognized that steel strand consisting of wound, multiple wires and made into cable bolts has proved to be a very effective means of improving mine stability. To date, most cables have utilized seven wire strand which has been grouted with some form of cement into boreholes in the size range 40 to 75mm diameter. While these have been found to operate satisfactorily and provide efficient rock mass reinforcement they are relatively expensive compared to conventional rock bolts, time consuming to install and do not operate at peak efficiency until the cement grout has cured.

The support requirements for coal mine roofs during roadway development are that, bolts must:

- \* be installed rapidly, and
- \* provide quick acting reinforcement and support to the strata before the face is advanced.

The development of the FLEXIBOLT flexible roof bolt originated from the idea of using a multiwire, single strand to take the place of a rigid bar type roof bolt. To satisfy the above requirements for roadway roof support, the flexible roof bolt needed to be designed so it could

be installed in the same manner as the rigid bolt and to gain maximum operator acceptance, installation with the same equipment would be preferable.

Details of the flexible bolt development are outlined in the paper together with the performance features of the product. Its properties as a roof reinforcement device are discussed, based on testing and initial field evaluations that have been completed to date. Finally, it is suggested that the performance offered by these flexible bolts provides coal mine operators, currently dependant upon high density support, with an opportunity to adequately reinforce roof strata with a relatively low density bolting pattern.

### DEVELOPMENT OF THE FLEXIBOLT FLEXIBLE ROOF BOLT (1)

For a multiwire strand to be acceptable to the Australian coal mining industry for use as a roof bolt, compatibility with the installation techniques and equipment used to install conventional rigid bar roof bolts was essential. To satisfy this, it had:

- to have a diameter of 22-23mm so it could be installed in a 27 - 28mm diameter hole,
- to be able to be spun through a resin cartridge and then to permit a plate/strap combination to be tightened against the roof, and
- be supplied in a range of lengths.

A major obstacle in the use of fixed length cables was to provide an end fitting which would allow installation in the conventional way, could transfer the full load capacity of the cable to an end plate and could be manufactured and supplied at a marketable price. A review of conventional cable terminations which were efficient at load transfer indicated that capels or cold worked swages were the only alternatives. Size and cost prohibited the use of these systems and therefore a new cable termination system had to be developed.

# 12th CONFERENCE ON GROUND CONTROL IN MINING

The solution which has led to the FLEXIBOLT flexible roof bolt involved the concept of threading the outer wires of the strand so that a nut could be threaded directly onto the strand.<sup>1</sup> The termination fitting consists of a nut supplemented by a number of threaded wedges which are confined by a collar. The collar acts against the plate/strap combination. When the termination fitting comes under load the wedges operate in similar way to a conventional barrel and wedge anchor allowing the full strength of the cable to be mobilized at the fitting.

To satisfy the practical requirements noted above, the strand needed to have:

- maximum density of steel wires within the overall diameter constraint,
- outer wires capable of being threaded, and
- sufficient rigidity to prevent "whip" during installation.

The strength of a steel strand depends on the strength of each individual wire, the number of wires and a stranding factor which accounts for the twist in the wires. Generally the strongest strand of any given diameter can be made by packing together the maximum number of small wires. However, for the flexible roof bolt application, the outer wires needed to be sufficiently large:

- to allow a thread to be formed,
- to provide adequate flexural rigidity, and
- to promote efficient bond development and load transfer.

The lay of the strand (direction of twist of the wires) is dictated by the spin direction to be used during installation: the Australian coal industry uses clockwise rotating machines so for the strand to "pump" the resin up the hole and for the outer wires to tighten during installation, the strand must have a left hand lay. Parallel lay in which all wires are wound in the same direction, allows steel area and inter wire contact to be maximised. This in turn maximizes the strand tensile strength for a given diameter and allows the end termination fitting to operate. In order to promote bonding the strand needs to be manufactured without grease or lubricant.

The prototype strand used to date has the following specification:

- Overall diameter: 23.3mm
- Lay (for coal mine application): Left Hand, parallel
- Construction: 1 x 21 (10/5 + 5/1)  
i.e. Ten outer wires and five inner wires plus five filler wires wound around a central wire.

<sup>1</sup>This concept is covered by Patent Applications and a granted Patent in South Africa.

Testing of this strand made from wires in the medium to high strength range by Bullivants Lifting & Industrial (BLI) gave an ultimate tensile strength (UTS) of up to 62.9 tonnes (2).

## LOAD TRANSFER CHARACTERISTICS

### Strand-Nut/Plate Termination Fitting

For a conventional rigid bar type bolt, full load transfer from the bar to the plate can be achieved by using a correctly designed nut threaded onto the bar. Since the bar and its thread are a solid continuous medium load transfer between the thread and bar is not a problem.

With a strand, this is not the case since the nut is only threaded onto the outside wires and therefore cannot act directly on the wires in the core. Essentially the load transfer limit of a conventional nut threaded onto a strand is either the nut thread strength or the tensile strength of the outside wires. In order to mobilize the strength of the inner wires, large frictional forces must be generated between the wires so that when the outer wires are stretched due to the applied force on the nut, then the inner wires are also stretched. This is achieved by radially compressing the outer wires onto the inner core wires with the tapered wedges which are part of the nut. The collar around the wedges seats against a plate. With this nut/tapered wedge termination, the bolt can be spun-in through a resin cartridge in the conventional manner and tightened against the plate. Displacement of the plate causes the collar to slide over the wedges which in turn, compress the wires and ensure that all wires in the strand are stretched due to the frictional force generated between the wires through confinement. This system has been tested up to 50 tonnes tensile load (machine limit) without failure of either the nut or the threaded strand.

### Load Transfer in the Encapsulated Length

Whilst there is extensive information and a high level of understanding of the bonding mechanisms and performance of prestressing strand bonded with cementitious grouts, there is little knowledge of the load transfer properties of other strand forms, particularly with resin grouts. Hence, a series of double embedment pullout tests has been carried out on the strand used for the prototype FLEXIBOLT flexible roof bolts and on high strength (X-bar)<sup>2</sup> 22mm diameter roof bolts. These were intended to provide directly comparable data for the two different types of roof support.

All the tests were prepared by spinning the bolts through a short resin cartridge in a two part, steel testing tube to cause the resin to extrude into the annulus in a similar manner to normal bolt installation. Loading caps were then fitted to the tubes and conventional double

<sup>2</sup>X-Bar bolts have a nominal yield and failure loads of 22 tonnes and 35 tonnes respectively.

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embedment tests were undertaken by pulling the two tubes apart. The testing tubes were manufactured from thick walled steel tube with a nominal internal diameter of 27mm and the inner surface roughened slightly to simulate the inner wall of a drill hole. All the tests were performed with Chemfix SCP4 resin. The 23.3mm strand was tested with two different outer wire strengths; 1570 MPa and 1770 MPa but otherwise with identical geometry and wire strengths.

Results of the tests with short encapsulated lengths are shown in Figures 1 and 2. Figure 1 shows pullout force versus displacement, whilst Figure 2 shows bond shear strength versus displacement, this removes differences due to the different bond lengths achieved in each test but assumes that the full bonded length is subjected to the same shear stress. Figure 1 shows that the initial stiffness (the gradient of the line) for both strand types was slightly higher than the X-bar stiffness but that both strand types reached a lower peak pullout force than the X-bar. The strand pullout curves then drop to about 65% of peak force but subsequently rise to a value similar to the initial peak. In contrast, once the X-bar reached its initial peak, the pullout force dropped rapidly to about 50% of its peak value and continued to decline to a lower residual value. The pullout characteristic of the strand is typical of prestressing strand in cementitious grout and is believed to result from a frictional type interaction between the strand and grout.

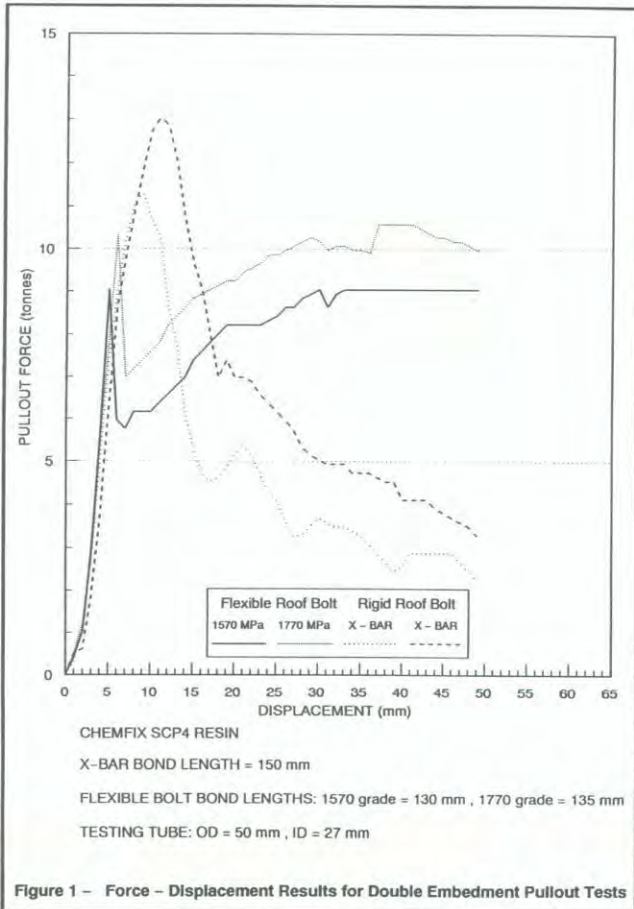


Figure 1 - Force - Displacement Results for Double Embedment Pullout Tests

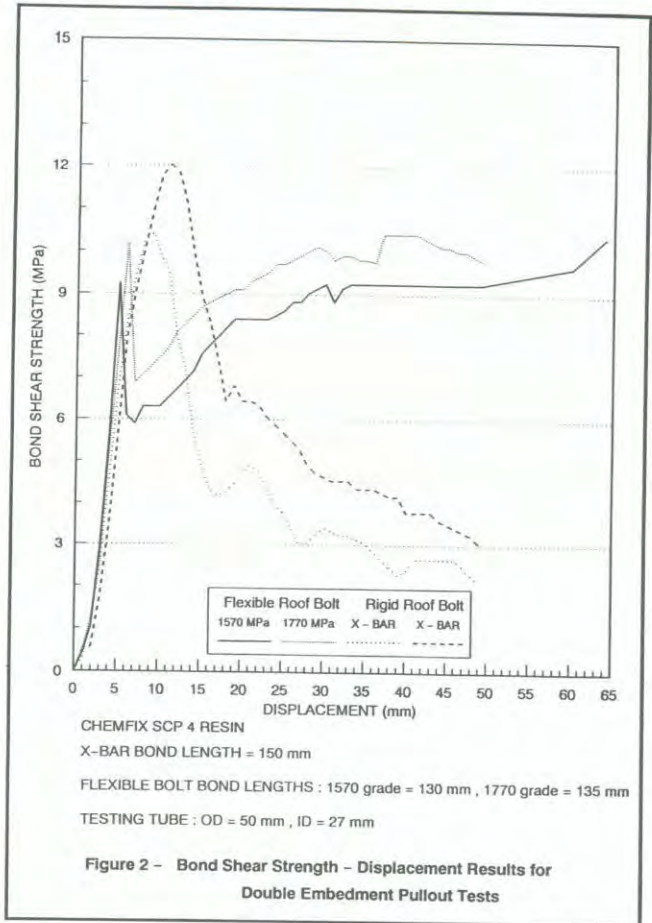


Figure 2 - Bond Shear Strength - Displacement Results for Double Embedment Pullout Tests

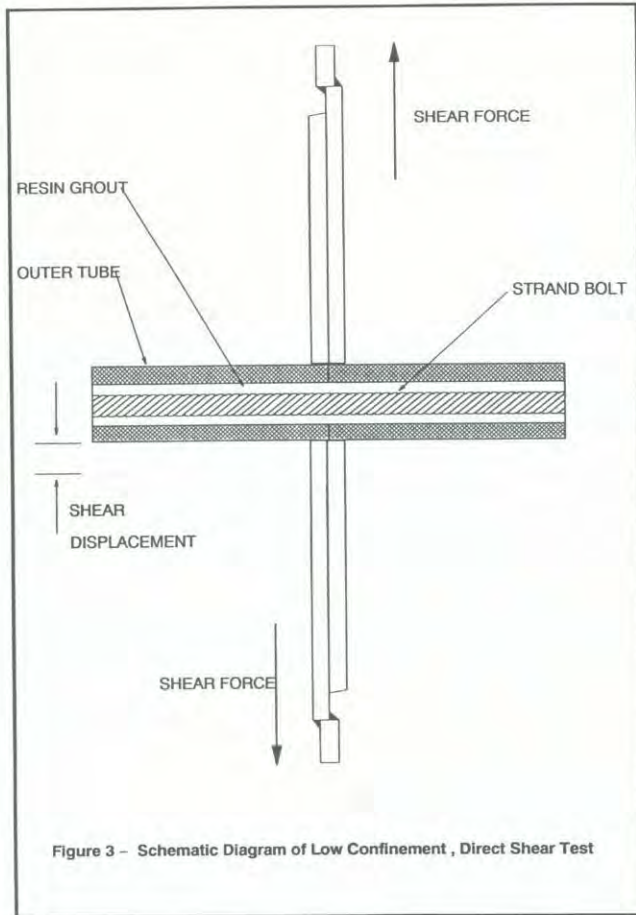
By removing variations due to bond length, Figure 2 probably provides a more accurate comparison of bonding properties and shows that for a given bond length, the ultimate pullout force for the strand will be about 15% less than that for X-bar. From these results, it can be expected that:

- \* strand will develop a slightly lower peak force than X-bar for a given bond length but that the strand peak force will be developed at about half the deformation of that required for the X-bar to achieve its peak,
- \* between 5 and 15 mm displacement, X-bar develops a higher force, but
- \* beyond 15mm of displacement the strand maintains a much higher support force.

It should be noted that the tests on strand were conducted with smooth, clean "as drawn" outer wires. Tests with prestressing strand have shown that lightly rusted strand has superior bonding performance to clean strand. Although no tests have been conducted to date, it is likely that the 23.3mm strand will mimic this characteristic.

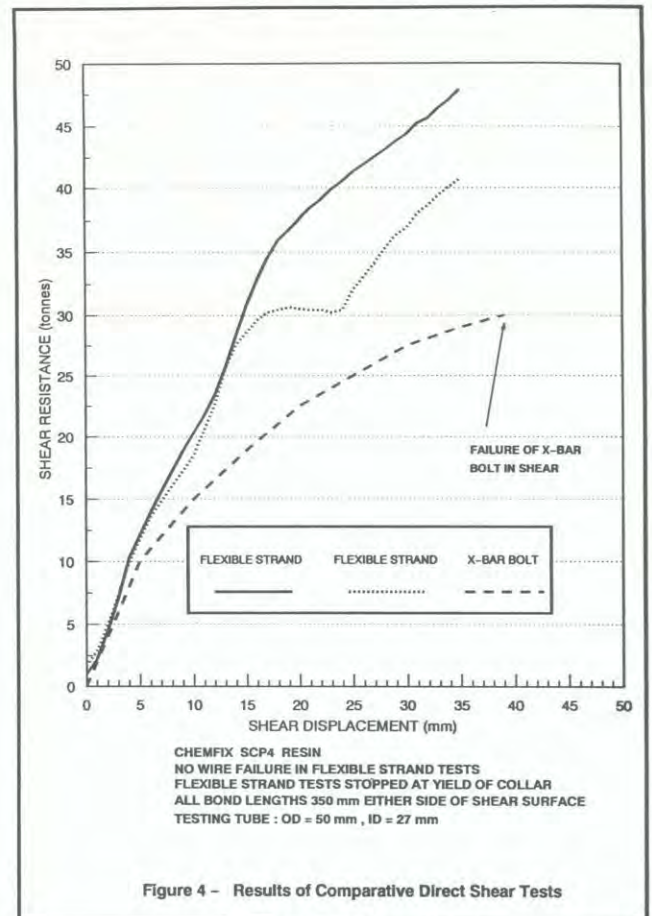
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Another aspect of reinforcement performance in the grouted portion of the bolt is the response of the bolt when subjected to shear. Strand and X-bar bolts have been tested, under low confinement, in direct shear tests in the laboratory. Test samples were prepared in the same way as for the double embedment tests prior to being installed in a guillotine apparatus of the type shown in Figure 3.



The results of comparative direct shear tests have been plotted in Figure 4 showing the increase in shear resistance across the interface with shear displacement at the interface. The results indicate that up to a shear resistance of approximately 10 tonnes, the performance of the X-bar bolt and the strand is similar but beyond that point the strand is significantly stiffer. The X-bar sample failed at about 30 tonnes whereas the strand results climbed to 41 and 47 tonnes respectively before the tests were stopped due to the tubes bearing on the outer wires of the strand. No wire failure occurred in either strand test.

The superior performance of the strand is due to its multi-wire construction which allows the wires to "flow" around one another rather than deforming as a solid unit.



## FIELD TRIALS

Field trials have been undertaken on the FLEXIBOLT flexible roof bolt to evaluate:

- installation techniques and machine compatibility, and
- reinforcement performance.

## Installation

The first installation trials were conducted at Tahmoor Colliery.

The strand bolts for these trials were manufactured from an initial prototype, 22.4mm diameter strand featuring 4.3mm diameter outer wire which was similar to a standard BLI product commonly used as guying rope. The intention of this trial was to determine whether a length of strand could be spun into a drillhole through a resin cartridge and, if so, to gain some indication of the bolt rigidity required to allow the bolt to be installed safely and comfortably. Three strand bolts were successfully installed and it was determined that increased bolt rigidity would be required. This led to the production of the larger 23.3mm diameter prototype strand specified above.

Further installation trials using different bolt lengths and various installation machines were then conducted on prototype bolts manufactured from the 23.3mm strand. The results of these are summarized in Table 1.

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## Reinforcement Performance

### Ellalong Colliery - Pullout Tests

Prior to a larger scale performance trial, pullout tests were performed at Ellalong colliery to determine comparative reinforcement properties for the flexible bolts and X-bar bolts in the field (3). The tests were conducted during the development of the tailgate of Longwall 10 and the test bolts were installed in freshly exposed roof within 5m of the development face.

To standardize the test hole diameter, each hole was drilled with a new bit, all the test bolts were anchored with identical anchors: CHEMFIX SDP2 Resin in 150mm x 25mm cartridges with the spin and hold times of 10 and 4 seconds respectively. During each test displacement of the bolt was measured at each force increment. Upon the release of the jack at the completion of each test on the flexible bolts, the jack was observed to rotate approximately 120°. This was due to the strand untwisting under load. Once the load was released, the strand returned to its normal state as the tests were designed not to exceed the elastic limit. The test installation and results are summarised in Table 2 with the force-displacement characteristic of each test plotted in Figures 5 and 6. The untwisting of the strand will also distort the load elongation characteristic shown in Figure 6 because the measured displacement includes a component due to the mechanical untwisting. However, it should be noted that the mean maximum pullout force achieved by the flexible bolts (17.7 tonnes) was nearly 21% greater than the mean maximum pullout force achieved by the X-bar bolts (14.6 tonnes) despite the mean bond length of the X-bar bolts being nearly 10%

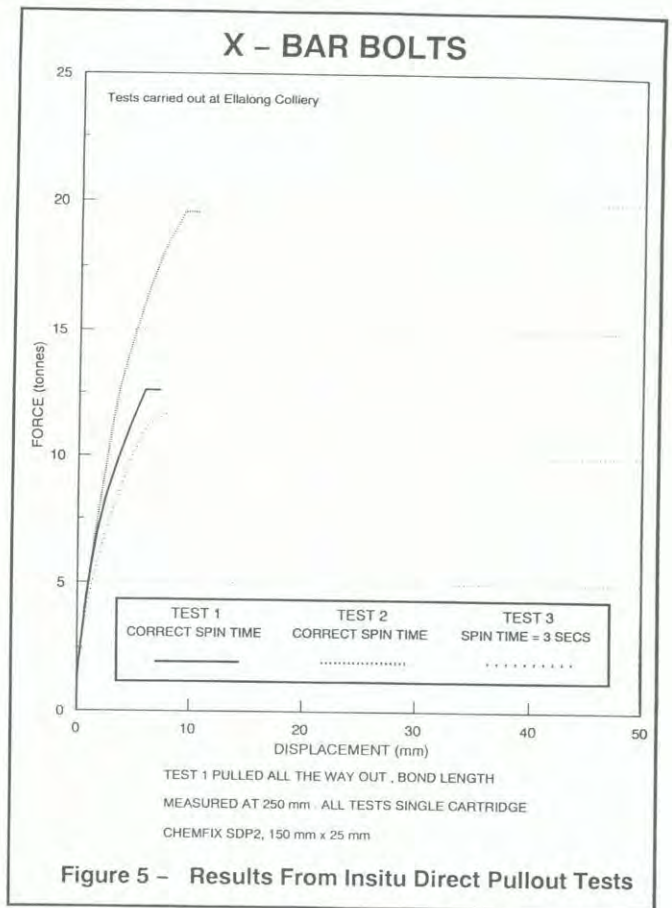


Figure 5 - Results From Insitu Direct Pullout Tests

TABLE 1 - SUMMARY OF INITIAL INSTALLATION TRIALS

Colliery	Aim of Trial	Results	Comments
WEST CLIFF	To determine the length of flexible bolt which could be installed in a single pass using a hand held bolter and attempting full encapsulation.	2.5m bolt, successful 2.7m bolt, successful 3.0m bolt, successful but slow owing to need to push bolt through resin 3.2m bolt, successful but very difficult	Height of roadway = 2.25m It is only practical to use a length of resin cartridge so that the bottom of the bolt does not protrude below the mixing dolly.
MOONEE	(1) To install a bolt longer than the coupled bolts being used, in a single pass with full encapsulation. (2) To test installation of flexible bolt from a hydraulic miner mounted rig.	3.0m bolt successfully installed with enough resin for theoretical full encapsulation.	Owing to drill rig geometry, bolt had to be pushed 200mm through resin before being spun.
ELLALONG	Preliminary installation trial prior to first field performance trial.	2.1m bolts installed successfully with full encapsulation using standard face equipment.	Performance trial proceeded.

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longer. No correction for the untwisting effect has been made in Figure 6.

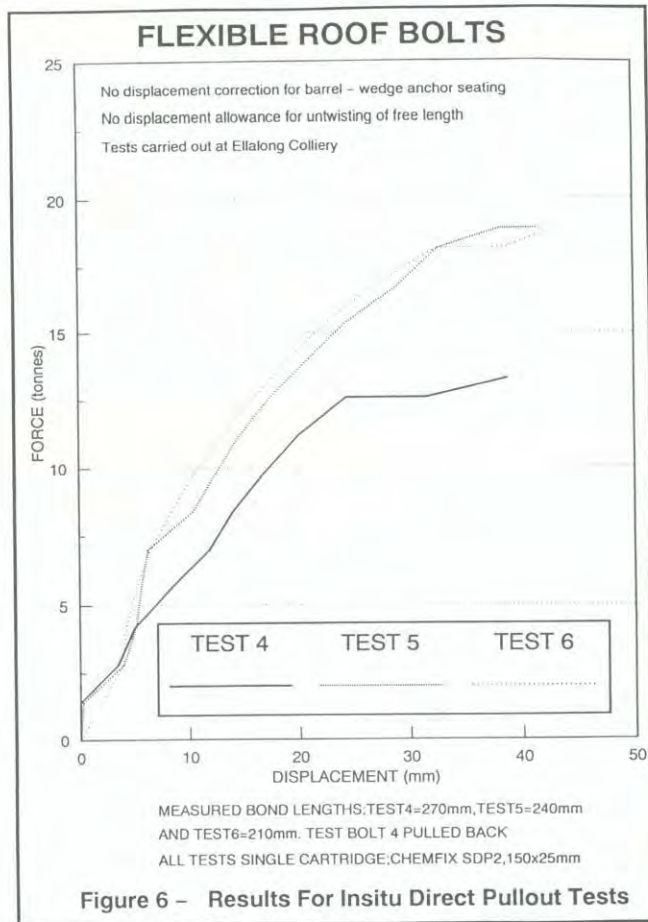


Figure 6 – Results For Insitu Direct Pullout Tests

Once the peak is reached, the pullout forces on all the X-bar bolts dropped to a much lower residual value (typically less than 5 tonnes) with further displacement whereas the flexible bolts were able to maintain their peak forces for up to 150mm of further extension. Whilst these tests confirmed the ability of the flexible bolt to develop and maintain high forces under field conditions, the untwisting of the free length which occurred in the tests allowed the bolt to unscrew from the grouted portion rather than shearing the grout. This accounts for the absence of the initial peak, observed in double embedment tests, in the field tests. An improved testing procedure was developed and further field tests were carried out at the Wyee State mine.

### Wyee State Mine – Pullout Tests

Modification of the field test procedure to prevent the free length of the strand untwisting involved encasing the unbonded portion of the bolt in a steel sheath and gluing it in place with high strength adhesive. The steel sheath was prevented from bonding to the resin by encasing it in a rubber material. The sheath necessitated installing the test bolts in a reamed hole. The final hole consisted of the portion to be bonded being 28mm in diameter and the remainder of the hole being 32mm in diameter to accommodate the sheathed section.

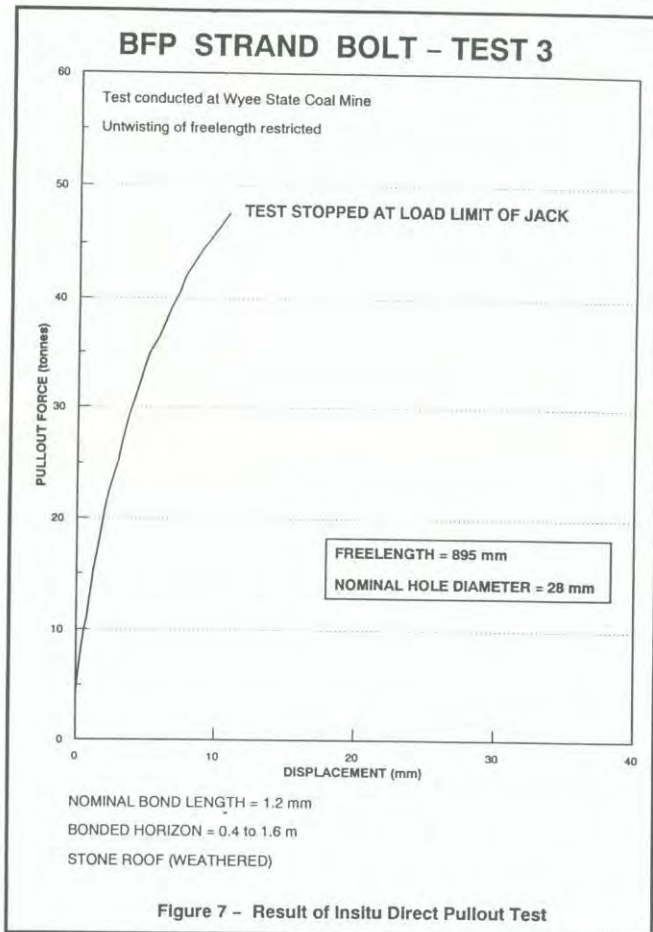
A series of six (6) tests was conducted. These were intended to examine the influence of preventing untwisting in field tests and the performance of the flexible roof bolts in roof strata (mudstone/claystone) which was relatively weak compared to the sandstone roof at Ellalong. The test installation and results are shown in Table 3 and a typical force-displacement curve is shown in Figure 7.

TABLE 2 – SUMMARY OF COMPARATIVE PULLOUT TESTS AT ELLALONG COLLIERY

Test	Bolt Type	Installed* Bond Length (mm)	Peak Pullout Force (tonnes)	Comments
1	X-bar	250 (m)	12.5	
2	X-bar	240–250 (e)	19.6	Only spun for 3 seconds.
3	X-bar	240–250 (e)	11.8	Bolt pulled back 50mm during 'hold' time.
4	Flexible Bolt	220 (m)	13.3	
5	Flexible Bolt	240 (m)	18.7	
6	Flexible Bolt	210 (m)	21.0	

\* 'm' = measured, 'e' = estimated

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The results of tests 1 to 5 in Table 3 reflect the performance of a fully bonded flexible bolt. Such bolts do not have any appreciable free length and therefore untwisting is not an issue in practice.

Thus, in weathered roof strata typical of that at Wye State, 1.2m is the embedment length required to generate the full tensile load of a fully bonded flexible bolt. Tests 1 to 5 were not intended to represent point anchored performance; since in that type of bolt installation, a free length will allow the bolt to untwist to some degree and rotate out of the bonded section. Test 6, where the free length was not confined, represents point anchored performance. The result from Test 6 indicates that, in this type of weathered strata, an anchor length probably in excess of 1.4m would be required to ensure anchor capacity at least equal to the tensile strength of the flexible bolt.

### Summary of FLEXIBOLT Flexible Roof Bolt Bond Strength Performance

The test results from the various laboratory and field pullout tests are summarized in Figure 8. This shows the peak pullout force achieved as the nominal bond length increases. Three lines have been included to indicate "bond shear strength" values of 5, 7 and 10 MPa. This allows a comparison to be made of bond strength performance from laboratory and field tests with different bond lengths, hole diameters and ground conditions. The only tests which failed to achieve a minimum bond strength of 7 MPa were tests in which either the jack load limit was reached or which had to be aborted due to

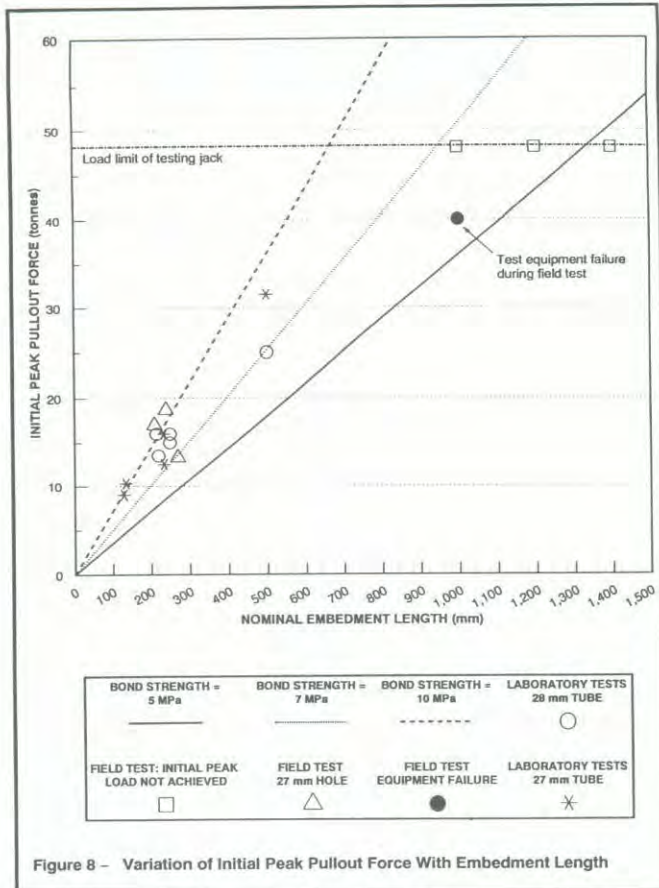
**TABLE 3 - SUMMARY OF PULLOUT TESTS AT WYEE STATE COAL MINE**

Test	Bolt Type	Nominal Bond Length (m)	Nominal Free Length (m)	Bond Horizon (m)	Peak Force (tonnes)	Displacement At Peak Force (mm)	Roof Type	Comments
1	FLEXIBOLT Flexible Roof Bolt	1	0.9	0.4-1.4	48*	32	Fresh Claystone	Incorrect spin time
2	"	1	0.9	0.4-1.4	40**	13	"	
3	"	1.2	0.9	0.4-1.6	48*	12	Weathered Claystone	
4	"	1.2	0.9	0.4-1.6	48*	15	"	
5	"	1.4	0.9	0.2-1.6	48	10	"	
6	"	1.4	0.9	0.2-1.6	42	13	"	Steel sheath not fitted.

\* Test stopped at load limit of jack.

\*\* Test stopped due to yield of barrel/wedge anchor used to grip strand.

## 12th CONFERENCE ON GROUND CONTROL IN MINING



premature yield of the testing equipment. With the long bond lengths in these tests it is probable that the bond strength capacity could exceed the nominal tensile strength of the bolt and therefore the ultimate bond strength could not be achieved in these pullout tests. A "bond shear strength" of 7 MPa or greater is regarded as offering 'good load transfer' (4).

### Preliminary Field Trial - Ellalong Colliery

In order to assess the ease of installation and work force acceptability of the FLEXIBOLT flexible roof bolt in a production environment and to compare the performance of FLEXIBOLT flexible roof bolts and high strength rigid bar roof bolts, a medium scale installation trial was conducted at Ellalong colliery. Ellalong colliery is a longwall operation currently mining at depths of about 500 metres. The mine is under the influence of very high horizontal stresses (>40 MPa) and has experienced some of the most extreme ground control difficulties in Australia (5). The mine installs relatively high densities of primary and secondary roof support: primary support consists (generally) of eight X-bar type bolts per W-strap with W-strap spacing between 0.7m and 1.0m. The colliery installs some 4,000 fully grouted, 10m long, twin strand "Birdcage"<sup>3</sup>

<sup>3</sup>"Birdcage" is a trademark of Rock Engineering Pty Ltd

cable bolts per annum as secondary support; current rib support practice involves full meshing of the ribs with two 1.2m long rib bolts being installed each side, 1.5 to 2.0m apart.

The colliery has adopted a three point research and development plan to remedy the geotechnical problems and the need for such intense ground support (6). This has involved evaluation of the principal driving force mechanisms, optimising mine and roadway design and the introduction of improved systems. The main outcomes so far are that lateral movement or shear is the principal roof deformation mechanism and the re-alignment of new longwall blocks to place the gateroads approximately parallel to the major horizontal stress field.

The trial of the FLEXIBOLT flexible roof bolts was conducted in No. 6 cut-through in the maingate of Longwall 10. This cut-through was orientated with the major stress across the roof and hence maximum deformation and bolt loading could be expected. The cut-through length (chain pillar width) was 37.5m and 72, 2.1m long FLEXIBOLT flexible roof bolts were installed in the central zone of the cut-through i.e. 9 W-straps at 8 bolts per strap spaced at 0.8 to 1.0m. The remainder of the cut-through was bolted in the conventional way with 2.1m long X-bar bolts at the same density. The resin cartridges were designed to give nominal full encapsulation with the flexible roof bolts and X-bar bolts. However, Ellalong experiences significant resin loss and it is probable that encapsulation was effectively only achieved from 0.6m to 2.1m (the end of the bolts).

Installation of the 2.1m long FLEXIBOLT flexible roof bolts was straightforward and once operators developed the "feel" for the bolt flexibility, normal bolt installation rates were maintained.

Identical instrumentation systems were installed in the two bolted areas. As the FLEXIBOLT flexible roof bolts could not be instrumented directly at this time, strain gauged X-bar type bolts additional to the bolting pattern were installed in both areas together with sonic probe extensometers. It was recognized that the instrumented X-bar bolt in the FLEXIBOLT flexible roof bolt zone would not give identical loading to the FLEXIBOLT flexible roof bolts: the intention was simply to provide an index by which the influence of the patterns of each bolt type (FLEXIBOLT flexible roof bolt or X-bar bolt) could be assessed. Results of vertical roof displacement from the sonic probe extensometers are presented in Figures 9 and 10. These show that displacement in both sections only occurred from 0 to 800mm into the roof horizon. This probably reflects the encapsulation achieved and that the first 0.5 to 0.8m of roof was coal which gives poor bond performance. No significant roof displacement was indicated above the 1.0m horizon.



## FLEXIBLE BOLT TRIAL ELLALONG COLLIERY

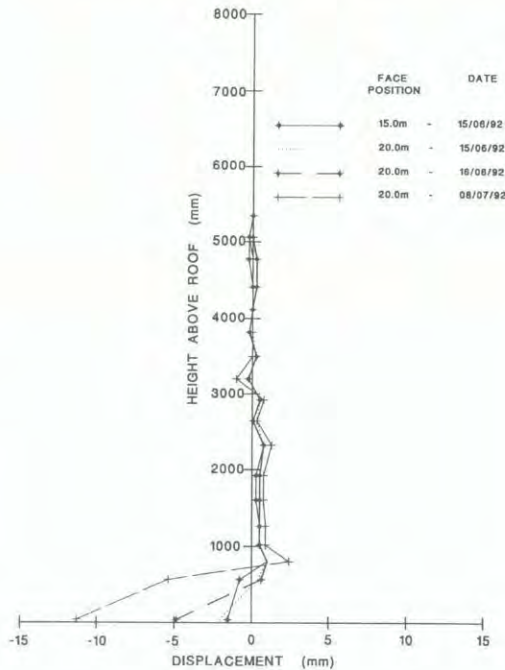


Figure 9 – Vertical Strata Displacement, X-Bar Site

## FLEXIBLE BOLT TRIAL ELLALONG COLLIERY

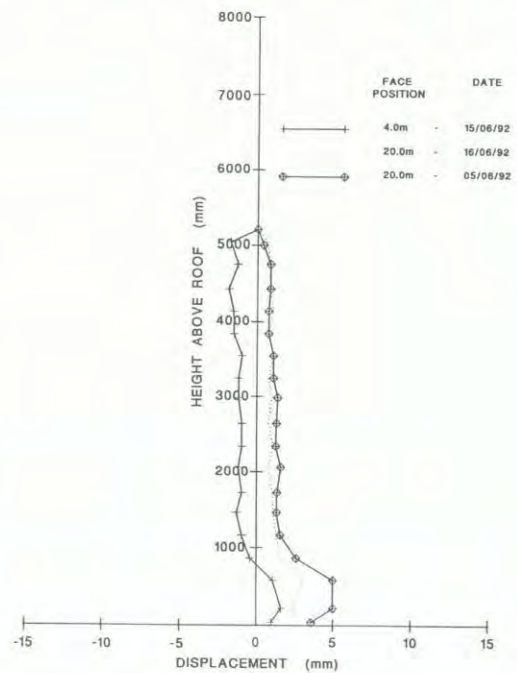


Figure 10 – Vertical Strata Displacement, Flexible Bolt Site

The axial loading results of the instrumented bolts are shown in Figure 11. In the flexible roof bolted section the instrumented bolt shows low loads throughout its length with a peak of about 8 tonnes being achieved at the 1.4m horizon. These low axial loads are consistent with the low vertical displacement indicated by the extensometers. However, a high load of 15 tonnes at the 1.4m horizon was observed on instrumented bolt A1 in the X-bar section whilst the other, bolt A2 showed a load of 26 tonnes (in excess of yield) at the 1.25m horizon. Examination of the bending moments, Figure 12, on the instrumented bolts revealed that bolt A2 had a high bending moment at the 1.25m horizon. Bolt A1 had a high bending moment at the 0.75 horizon but no significant bending was apparent at the 1.4m horizon.

The instrumented bolt in the flexible roof bolt section did not display any significant bending. These results imply the following:

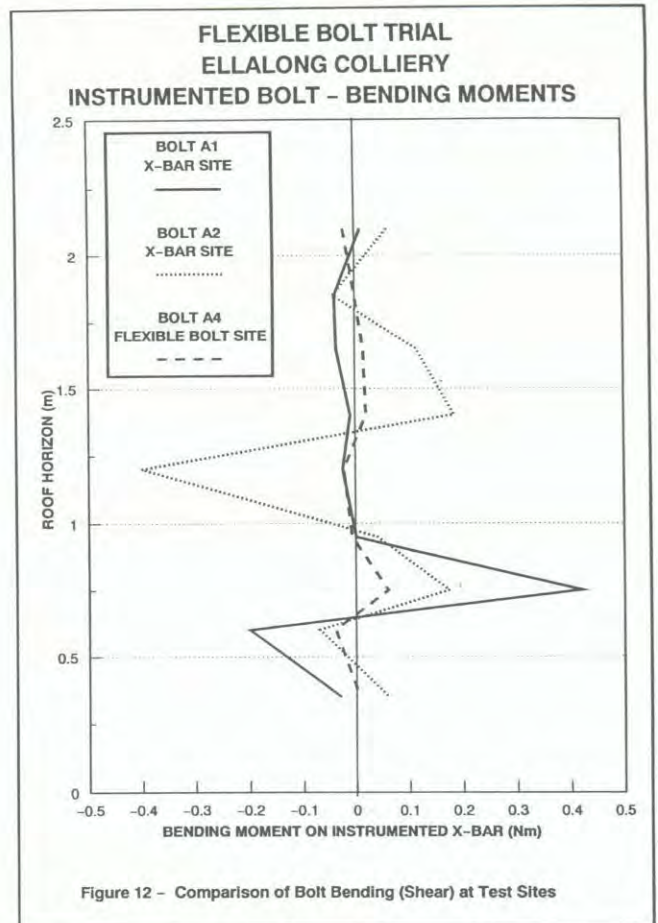
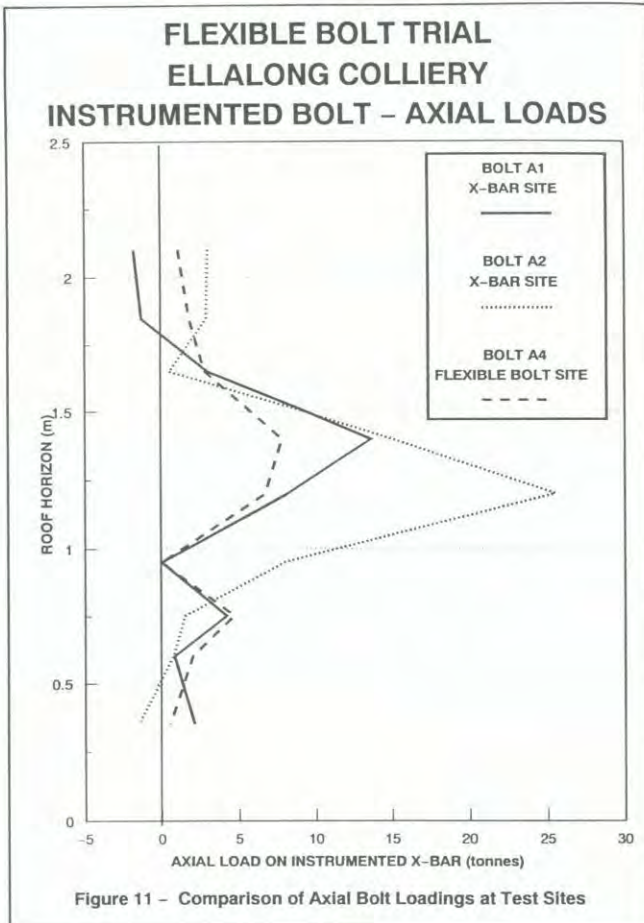
- Significant vertical displacement did not take place at either site particularly in the bonded portion of the bolted horizon.

- The instrumented bolts in the X-bar section were subject to higher bending moments than the instrumented bolt in the FLEXIBOLT flexible roof bolt section. Hence it is concluded that the superior shear resistance of the FLEXIBOLT flexible roof bolt (Figure 4) was more effective in restricting shear movement in the roof strata.
- The high axial load experienced by bolt A2 at the 1.4m horizon was due to the roof shear at the same horizon.
- The high axial load in bolt A1 must be a response to the roof shear because virtually no vertical strata displacement was detected.

The overall conclusion of the colliery from these results was that "further demonstration is warranted to confirm the potential of the FLEXIBOLT<sup>4</sup>. The trial demonstration should consist of 30m of roadway reinforced with FLEXIBOLTS<sup>4</sup> of varying densities where they will be subject to longwall abutment loading" (6).

<sup>4</sup>The FLEXIBOLT flexible roof bolt.

# 12th CONFERENCE ON GROUND CONTROL IN MINING



## CONCLUSIONS AND ONGOING WORK

The overall conclusions and developments in the use of a steel strand as a primary support system are as follows:

- A high load capacity strand (nominal UTS = 60 tonnes) has been used with current coal mine bolting technology as a primary support by providing a thread on the strand (FLEXIBOLT flexible roof bolt) and a nut which permitted the bolt to be spun conventionally through resin.
- A threaded end fitting has been developed capable of developing a plate load in excess of 50 tonnes.
- The FLEXIBOLT flexible roof bolt developed similar initial bond strength and stiffness to high strength (X-bar) bolts.
- The FLEXIBOLT flexible roof bolt has superior residual post slip bond strength compared to X-bar bolts.
- The shear resistance offered by the FLEXIBOLT flexible roof bolt is significantly greater than that offered by X-bar bolts.

- Field trials have indicated that the FLEXIBOLT flexible roof bolt:
  - \* allows bolts longer than the available headroom to be installed in a single pass,
  - \* can achieve bond strengths equivalent to those designated as able to give "good load transfer", and
  - \* can reduce lateral movement in roof strata subject to high horizontal stress fields.

Results of trials to date indicate that FLEXIBOLT flexible roof bolts have the potential to allow operators to reduce bolting density yet still maintain adequate roof support and reinforcement.

FLEXIBOLT flexible roof bolt evaluation is continuing through a research project funded by the Australian Coal Association Research Programme (ACARP) and contributions from the participating collieries. At the time of preparing this paper, a further trial was in progress at Ellalong colliery to examine the impact of longwall abutment stresses on roofs reinforced with various densities of FLEXIBOLT flexible roof bolts; work had commenced at Angus Place Colliery on the installation techniques and bond performance prior to trials using long (>3m) FLEXIBOLT flexible roof bolts as both primary support installed at the face and secondary support installed as a back-bye operation.

# 12th CONFERENCE ON GROUND CONTROL IN MINING

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Note: Bullivants Lifting & Industrial (BLI) were formerly known as Bullivants Lifting Gear (BLG).

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