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LOAD TRANSFER CHARACTERISTICS OF PLAIN AND SPIRAL CABLE BOLTS TESTED IN NEW NON ROTATING PULL TESTING APPARATUS

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ABSTRACT: The load transfer mechanisms of cable bolts differ from normal rebar bolts. Cable bolts used in mines are basically steel strands with different constructions depending on the number of wires or elements and the way that these elements are laid. Tendon bolts (rebar and cable) are normally evaluated for strength and load transfer properties. The strength of tendon can be carried out by tensile failure tests, while the load transfer strength is evaluated by pull and shear strength tests. Short Encapsulation Pull Testing (SEPT) is used to study of the load transfer capacities of tendons, and can be undertaken both in the laboratory and in situ. A new apparatus known as Minova Axially Split Embedment Apparatus (MASEA) was used to study load-displacement characteristics of smooth versus spiral profile cable bolts. Minova Stratabinder grout was used for encapsulating 400 mm long 19 wire 22 mm diameter superstrand cable in the embedment units. The anchorage of the cable on two sides of the embedment apparatus were intentionally installed at different lengths, to allow the cable to be pulled out from one side of the anchorage. The spiral wire strand cable bolts achieved higher peak pull-out load at minimum displacement in comparison with smooth surface wire strand. The peak pull out force increased with the age of encapsulation grout. The MASEA was easier to assemble and test at a short period of time, thus allowing quick and repeated tests to be undertaken.

INTRODUCTION

For several decades now, cable bolting systems have been used for ground reinforcement and stabilisation in mines. Initially cable bolts were used for surface stabilisation structures such as dams and slopes, prior to their adoption in mines (Gillott and Mieville 1964). The use of cable bolts in underground mines initially began in metal mines and later on in coal mines. There are currently more that dozen types of cable bolts, classified into five main categories used in Australian mines. These are; (a) smooth or plain surface cable bolts; b) bulbed; c) nut caged; d) spiral and indented cable bolts; e) a mix of plain and spiral cable bolts. With the exception of Garford twin cables, most cable bolts used in Australian coal mines are made of seven, nine and 19 wire constructions. The 19 wire strand is of Warrington Seal Construction. The seven wire cables have six outer wires wrapped around the central core wire, which is known as the centre or king wire. However, the 19 wire cable has two layers of wires consisting of nine 5 mm diameter outer wires and; nine 3 mm inner layer wires, all wrapped or laid around the 7 mm inner or king wire. Recently a new nine wire cable was introduced to the Australian mines, which consisted of alternate smooth and spiral wires.

For a cable bolt support system to be effective, the loads have to be successfully transferred from the rock to the cable through the grouting materials. The increase in axial forces within the cable occurs during the movement of the rock mass at shear planes and bed separations. Thus the anchorage applied in the borehole, can be enhanced by various strand's outer wires surface roughness such as indentations and spiral profiles as well as the presence of birdcages or bulbs.

During installation of cable bolts chemical resin grouts, cementitious grouts or a combination of both are used. The main method of assessing the long tendons performance is by evaluating both tensile and shear performance.

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The early interest in assessing the performance of cable bolts dates back to the work of Fuller and Cox (1975). Since then there has been a growing number of testing techniques and procedures reported in various publications because of the increased variety of cable bolt design and size. The current research on cable bolt assessment used as secondary support system.

The earlies method of determining the load transfer capacity of cable bolts was by encapsulating one end of the cable in a steel tube, while the other free end was to be used to pull the cable out using a tensile testing machine. This system was later extended to Double Embedment Pull Test (DEPT). The pull testing with double embedment installation was mostly used for tensile failure test rather than load transfer studies, as reported by Clifford *et al.,* 2001. This methodology of testing was subsequently adopted in the British Standard BS 7861- Part 2 (1997) and later in amended edition of BS 7861- part 2 (2007). This suggested the double embedment method for cable pull testing to failure, whereby a suitable length of the cable was installed in embedment tubes with an internal diameter of 35 mm and outside diameter of 63.5 mm. The internal surface of each tube section was machined to a 2 mm pitch, 1 mm deep thread to prevent failure at the grout tube boundary. Two tubes, each 450 mm in length were used to install the end sections of cable bolt in each tube, which were butted together. The DEPT has been used both for the evaluation of the cable ultimate strength as well as for load transfer capacity studies.

Thomas (2012) reported on the load transfer of post-groutable cable bolts and described the fundamental aspects of cable bolt load transfer and testing procedures. He critically reviewed various methods of cable bolt pull out tests and undertook a series of pull tests on 14 cables types using a modified version of the Laboratory Short Encapsulation Pull Test (LSEPT) apparatus initially developed by Clifford *et al.,* (2001). Thomas (2012) reported on variations in load displacement profiles between plain and profiles surfaces of the different cable bolts.

Thomas (2012) described the fundamental aspects of cable bolt load transfer, and testing procedures, focusing on the latest innovation of the testing systems applied and on their significance. Citing the study undertaken by Clifford *et al.,* 2002, which allowed an amount of assessment of the grout to rock interface and hole rifling, that better simulated the underground environment, however Thomas (2012), questioned the use of high 10 MPa confining pressure of the biaxial force applied on the rock anchors, as being inconsistent with the underground ground pressure environment. Subsequently Thomas (2012) modified the Clifford developed system by replacing the biaxial pressure cell with a thick walled steel cylinder and the whole assembly was locked up together with an anti-rotation device to prevent the cable from unwinding out of the core when the pull load was applied as shown in Figure 1. Other points for noting were:

- The diameter of the sandstone medium was 142 mm and the UCS values ranged between 19 to 25 MPa, and
- A barrel and wedge was embedded in the cementious or resin grout inside the concrete column inside the steel tube.

Hagan *et al,* (2014), in the ACARP project C2010, reported a chronological review of different pull testing techniques of since the mid-1980's and extended the non -rotating cable concept developed by Thomas (2012) during pull testing to include:

1. Testing of the cables in concrete cylinders.
2. Applying confining pressure by enclosing the concrete cylinders in two section steel cylinders.

Studies were subsequently undertaken to gauge the sensitivity of several parameters; the strength of the concreted that is used for testing; the diameter of the borehole size and thickness of grout encapsulation in relation to the concrete strength. Further studies carried out include the following:

- The development of an axial loading test procedure for cable bolts used in Australian underground mine,
- Development of a new laboratory-scale teste facility for pull testing of various cables,
- Optimisation of the concrete cylinder size that lead to the optimisations of pull testing of various cable bolts and

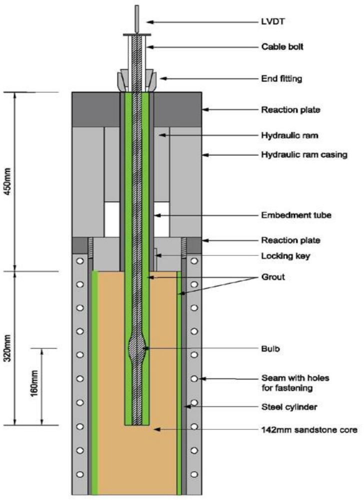

Figure 1: A modified Laboratory short encapsulation pull test (Thomas 2012)

Further amendments of single embedment length pull-out tests include:

- Cable testing in unconfined as well as confined condition,
- Confined concrete sample diameter increased from previously used 142 mm to 300 mm, the latter being the most suitable size,
- The concrete sample enclosed in a steel cylinder (axially split) and assembled by bolting together two half cylinder making it easier to de assemble.

Figure 2 shows the UNSW assembled cable pull testing facility (Hagan *et al*., 2014) and Chen *et al.,* 2014).

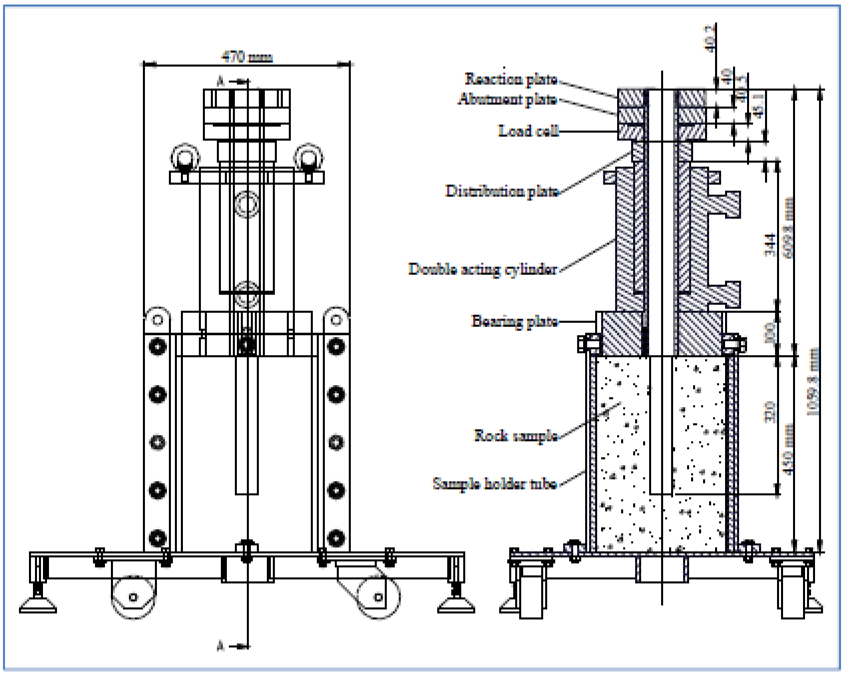

Figure 2: UNSW LSEPT pull testing apparatus (Chen *et al.,* 2014)

From various tests procedures reviewed it is obvious that in each test described, a significant amount of wastage occurs in terms of material used, and cost, because of;

- The need for steel tubes with regard to testing using single or double embedment tubes. These tubes are only used once, thus multiple tests require more tubes.
- The need for availability of rock samples for cable bolt installations, requiring sample preparation for cable installation, and
- In the case of the latest short encapsulation testing as developed by Hagan, requiring 300 mm diameter concrete test samples and consumable anchor tubes.

In this paper a new instrumentation is described that eliminates the need for rock or concrete samples and other consumables. The system will permit repeated test to be undertaken economically and at a much faster rate, and the new system can be further modified to allow various diameter cables to be tested, and the system is particularly suited for comparatives cable bolt design tests.

AXIALLY SPLIT DOUBLE EMBEDMENT PULL TESTING

Design

Figure 3 shows a detailed drawing of the axially split SEPT apparatus. Developed by Minova Australia, the apparatus has two embedment sections, with each section consisting of two half blocks of steel with semicircular holes carved out in the middle. Two sections are butted together and bolted tight using eight Allen socket head bolts, 50mm long and 8 mm in diameter. Thus, the central hole becomes 30 mm diameter hole 250 mm long. The internal surface of the central hole has grooves 3mm deep and spaced 10 mm apart as shown in the detailed design in Figure 3. The objective is to allow effective anchorage of the resin/grout to the outer hole wall. A rectangular 10 mm thick steel sleeve, inserted on the assembled embedment apparatus ensured non-rotation of the anchored cable during pull out testing. A 100 mm long window on one side of the sleeve was cut for viewing of the pulled out cable as shown in Figure 4. The cable anchorage is achieved using chemical resin or cementitious grout and re-use of the capsule is possible after each completed test. The removal of grout post-test and cleaning of the steel capsule for re-use was found to be easier with grouts in comparison to chemical resin.

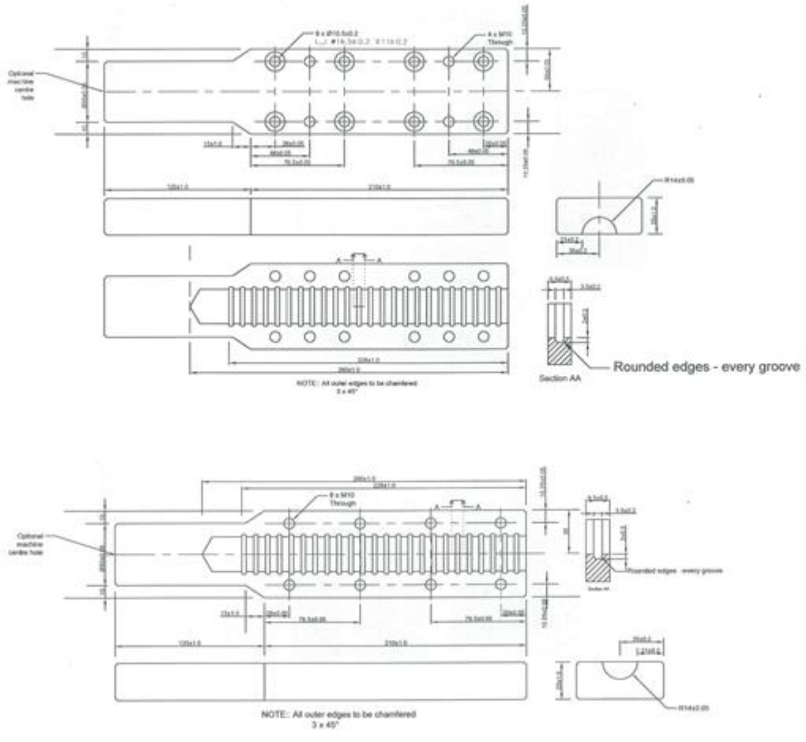

Figure 3: Detail drawing of the Minova axially split SEPT assembly

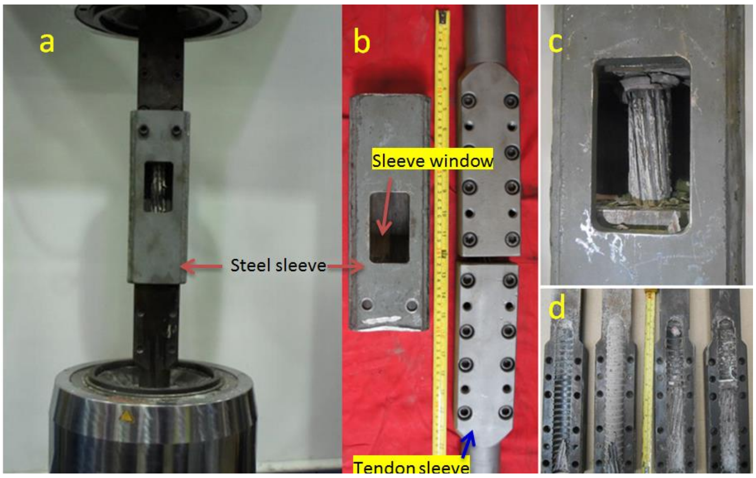

Figure 4: Axially split double embedment pull testing apparatus

Pull testing

The objective of the study was to compare the pulling force between plain and spirally profiled cables. In this study 22 mm diameter 19 wire super-strand cable bolt sections were tested. Both plain and spiral cables were used and each tested cable piece consisted of 400 mm long sections with free ends welded to ensure the wiring assembly remains intact during pulling. Each cable was anchored in the steel sleeves at different lengths. The aim was to let the cable to be pulled-out from the shorter side sleeve leaving the other side to act as intact anchorage. Accordingly, one side of the cable was encapsulated to a depth of 230 mm and the other at 170 mm. This arrangement was necessary to let cable to be pulled out from one side only to gain better understanding of pull out behaviour between plain and spirally profiled cables. Figure 6 shows a post-test view of the cable in opened apparatus.

Results and analysis:

Figure 5 shows the load-displacement graphs of six tests. Tested cables were encapsulated in the holders using the same resin of various ages. Ages of encapsulated grout were; four days, one week, and one month. Figure 6 shows the view of the split assembly after pull testing. Table 1 shows the initial peak load of various tested cables and optimum displacement.

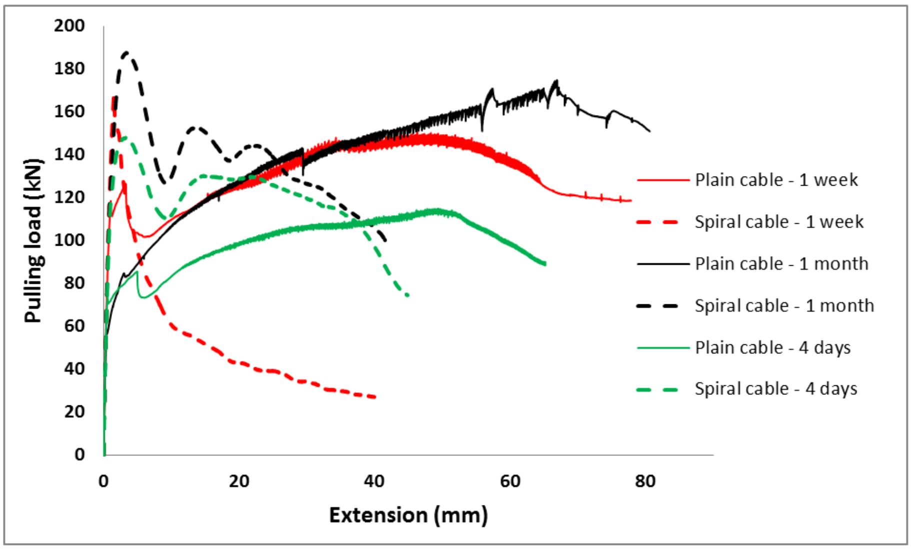

Figure 5: Load – displacement graphs of pull testing of cables at different encapsulating grout ages

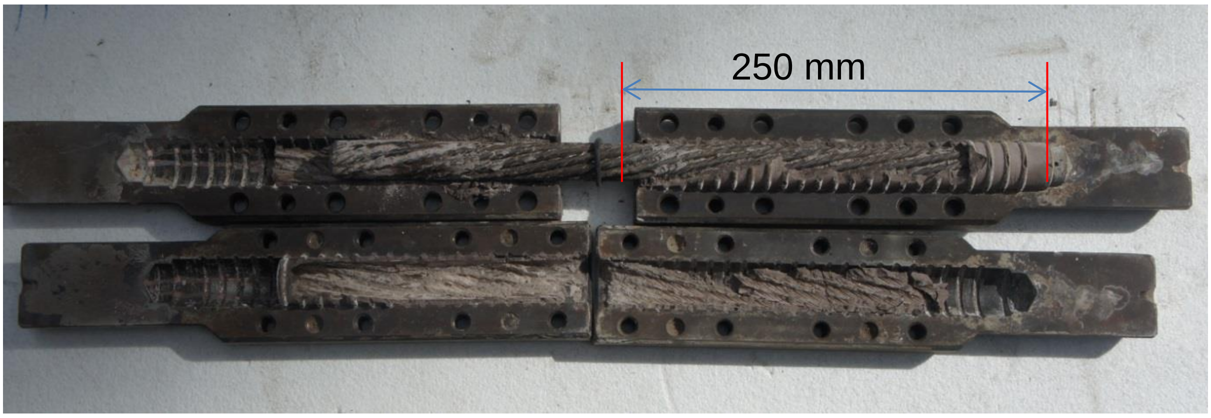

Figure 6: Post-test two halves of the pull out apparatus with encapsulated cable bolt

Table 1: Pulled out peak load values of tested cables with grout ages of four days, one week and one month of encapsulations, for both smooth and spiral wired cable strands

Parameter	Four days encap.		One week old encap		One month old grout	
	Plain	Spiral	Plain	Spiral	Plain	Spiral
Peak Load(kN)	115.0	148.2	150.8	68.1	174.9	187.7
Displacement (mm)	50	2.5	46.0	1.5	66.17	1.5
Bond strength (kN/mm)	0.676	0.87	0.887	0.989	1.029	1.10

The load - displacement graphs of six tests shown in Figure 5 indicate the following:

1) When pulling the spiral cables, all peak loads occurred at displacements of less than 5 mm however, the respective peak loads for plain cables were significantly greater.
2) The displacements at the peak loads were generally higher for spiral wire cables,
3) The profiles of spiral and plain cable pull loads as well as their respective displacement were in agreement with the load-displacement profiles reported by Thomas (2012) for tests made in sandstone blocks. The incorporation of the steel sleeve on the pulling apparatus shown in Figure 5 clearly demonstrates its effectiveness in elimination of cable rotation during pull testing. AAs expected, the bond strength of the tested samples was noted to increase with encapsulation grout curing age. The peak load per millimeter of the encapsulated plain cable length ranged between 0.676 kN/mm for four day grout cure to 1.029 kN/mm for one month old cure. Similarly for the spiral profile these values ranged between 0.87 kN/mm and 1,104 kN/mm respectively. These values were not much different from the test results of Thomas carried out on 19 mm diameter Hilti cables of 1.10 kN /mm for spiral cable and 0.672 kN/mm for the plain cable respectively, bearing in mind that; a) the embedded cable length conducted by Thomas (2012) in sandstone block was 320 mm; and b) the resin used was different from the Minova Mix and Pour resin used in this Peak load achieved with plain cable bolts occurred at greater displacement, irrespective of the grout or resin installtion age. The profiles of load displacement are in agreement with the results of Thomas (2012).
4) The use of the steel encapsulation frame allowed repeatable, faster and economical tests.
5) The MASEA test apparatus was designed for pull testing of limited diameter tendons. Figure 7 shows an alternative apparatus for pull testing of different diameter tendons. This new apparatus is named as Multi Diameter Laboratory Short Encapsulation test (MDLSET) apparatus. This instrument will permit pull out tests of cables of different diameters.
6) While the use of steel frame is no substitute to testing of the cables in rocks and in composite materials such as concrete, nevertheless, test results are consistent and with similar results reported by Thomas in sandstone and steel frame.

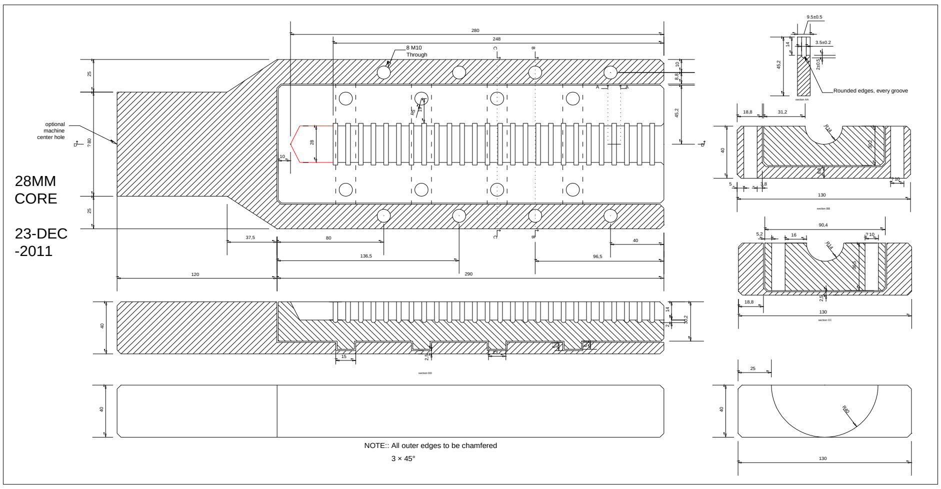

Figure 7: A drawing of multi diameter laboratory short encapsulation test instrument

CONCLUSIONS

A new Minova pull out instrument has been developed for testing cable bolts. It is simple in design and construction. Its main benefit is that it is a fast method which requires no additional testing material other than the resin or grout for cable encapsulation. The current instrument is designed to suit rock bolts and cable bolts of 22-24 mm diameter. However the system can be extended to permit testing of cables of any diameter and bulbs. This has been achieved by enlarging the system and incorporating separate sleeves of the internal grooves fitted in to outer shelves of the instrument and is known as MDLSET.

Using the MLSEPT instrument it was found that spiral cables pull loads were higher than and occurred at shorter displacement in comparison with smooth cables. Also the peak loads were found to increase with the curing time age of encapsulation irrespective of the cable type.

ACKNOWLEDGEMENMT

The pull testing instrument described was designed and constructed by Minova Australia and has been used to carry out various tests to prove the viability of the equipment for fast and economical in application. The authors are grateful to Minova for permsion to use this instrument for various for various testing. The new MDLSET type design system as reported in this paper has been developed and pproved successful.

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