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An experimental study of axial load transfer mechanisms of cable bolts using axially split embedment apparatus

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Abstract

The load transfer mechanisms of cable bolts differ from those for normal rebar bolts. The cable bolts used in mines are basically steel strands with different constructions depending on the number of wires or elements and the way they are laid. Tendon bolts (rebar and cable) are normally evaluated for their strength and load transfer properties. The tendon strength can be evaluated by the tensile failure tests, while the load transfer strength is evaluated by the pull and shear strength tests. Short Encapsulation Pull Testing (SEPT) is normally used to study the load transfer capacities of tendons, and it can be undertaken in both 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 embedment units. The anchorage of the cable on the 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 a higher peak pull-out load at a minimum displacement in comparison with the smooth surface wire strand. The peak pull out force increased with the age of encapsulation grout. The use of MASEA was easier to assemble and test at a short period of time, thus allowing the quick and repeated tests undertaken.

Keywords: *Experimental Study, Axial Load, Cable Bolts*.

1. Introduction

For several decades now, cable bolting systems have been used for ground reinforcement and stabilization in mines. Initially, cable bolts were used for surface structure stabilizations such as dams and slopes prior to their adoption in mines [1]. The use of cable bolts in underground mines initially began in metal mines and later on in coal mines. There are currently more than a 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; and 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 center 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 has been introduced to the Australian mines, which consist of the 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. These axial forces can be applied via the bearing plate or as a result of horizontal movement of the rock mass at shear planes and bed separations. Thus the anchorage applied in the borehole can be enhanced by buttons for opening the strand called birdcages or bulbs.

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

The early interest in assessing the performance of cable bolts dates back to the work of Fuller and Cox (1975) [2]. Since then, there has been a growing number of testing techniques and procedures, as reported in various publications by various researchers due to the increase in the variety of cable bolt design and size. The primary focus of interest, these days, is on cable bolt assessment as secondary support systems.

The earliest method used for determining the load transfer capacity of cable bolts was by encapsulating one end of the cable in a steel tube, with the other free end to be used of pulling 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 the tensile failure test rather than the load transfer studies, as reported by Clifford et al., 2001. This testing methodology was subsequently adopted in British Standard BS 7861-Part 2 (1997) [3] and later amended edition BS 7861-part 2 (2007). This suggested the double embodiment method of pull testing of cable to failure, whereby a suitable length of the cable was installed in embedment tubes with an internal diameter of 35 mm and an outside diameter of 63.5 mm. The internal surface of each tube section was machine threaded to a 2-mm pitch 1-mm deep thread to prevent failure on the grout tube boundary. Two tubes, each 450 mm in length, were used for installing a section of cable bolt in each tube section, which were butted together. The DEPT was used both for the evaluation of the cable ultimate strength and the load transfer capacity studies.

Thomas (2012) [4] reported the load transfer of post-groutable cable bolts, and described the fundamental aspects of the cable bolt load transfer and testing procedures. Thomas (2012) [4] 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) [5]. Thomas (2012) [4] reported variations in load displacement profiles between plain and profiles surfaces of the different cable bolts.

Thomas (2012) [4] 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) [4] 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) [4] 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 as follow:

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

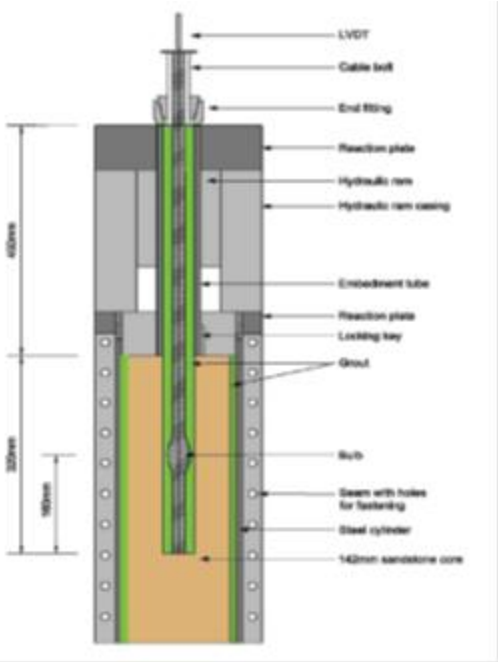

Figure 1. A modified laboratory short encapsulation pull test [4].

Hagan, et al. (2014) [6] ACARP project C2010 reported a chronological review of different techniques of pull testing since the mid-1980's, and extended the Thomas (2012) [4] non-rotating cable concept during pull testing to include:

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

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

- Development of an axial loading test procedure for cable bolts used in Australian underground mines;
- Development of a new laboratory-scale test facility for pull testing of various cables;
- Optimisation of the concrete cylinder size that leads to the optimizations of pull testing of various cable bolts.

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

- Cable testing in unconfined as well as confined conditions;
- 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 cylinders making it easier to de-assemble.

Figure 2 shows UNSW assembled cable pull testing facility [6-7].

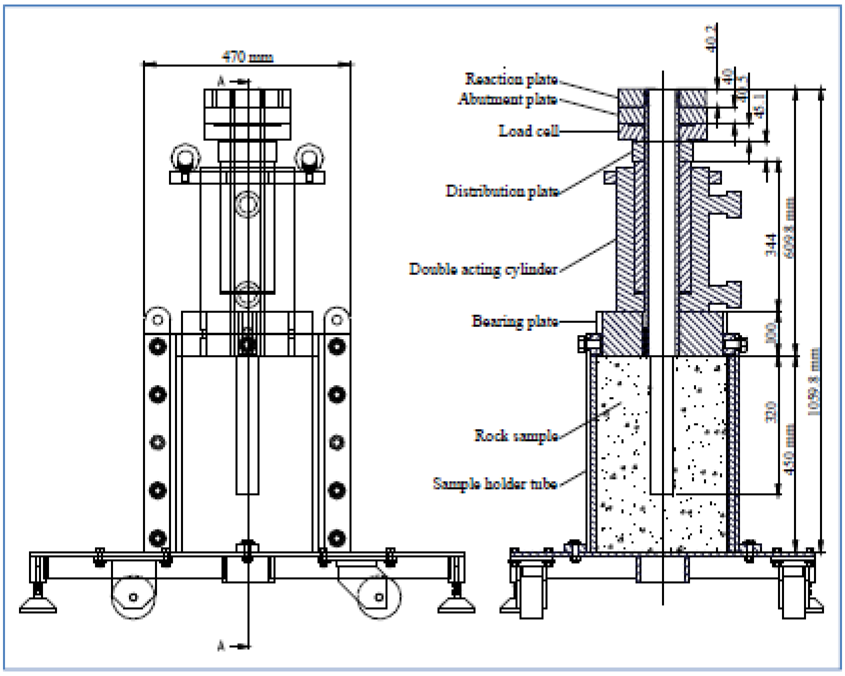

Figure 2. UNSW LSEPT pull testing apparatus [7].

From the various test procedures reviewed, it is obvious that in each test described, a significant amount of wastage occurs in terms of the materials used and the cost, due to the following reasons:

- The need for steel tubes with regard to testing using single or double embedment tubes. These tubes are only used once, and thus multiple tests require more tubes.
- The need for availability of rock samples for cable bolt installations, requiring sample preparation for cable installation.
- 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 permits repeated tests 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 comparative cable bolt design tests.

2. Axially split double embedment pull testing

2.1. Design

Figure 3 shows a detailed drawing of an axially split SEPT apparatus. Developed by Minova Australia, this apparatus has two embedment sections, with each section consisting of two half blocks of steel with semi-circular holes carved out in the middle. When the two sections are butted together and bolted tight using eight Allen socket head bolts, 50-mm long and 8-mm in diameter, the central hole will become a 30-mm diameter hole and 250-mm long. The internal surface of the central hole has grooves 3-mm deep and spaced 10-mm apart, as shown in the detailed design shown 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 ensures non-rotation of the anchored cable during the pull-out testing. A 100-mm long window on one side of the sleeve was cut to view the pulled out cable, as shown in Figure 4. Cable anchorage is possible using chemical resin or cementitious grout, and the 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 with chemical resin. Once the SEPT apparatus is assembled, it is positioned inside the tensile testing instrument (see Figure 4a), where only one side is subjected to tensile displacement.

2.2. Pull testing

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

3. Results and analysis

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

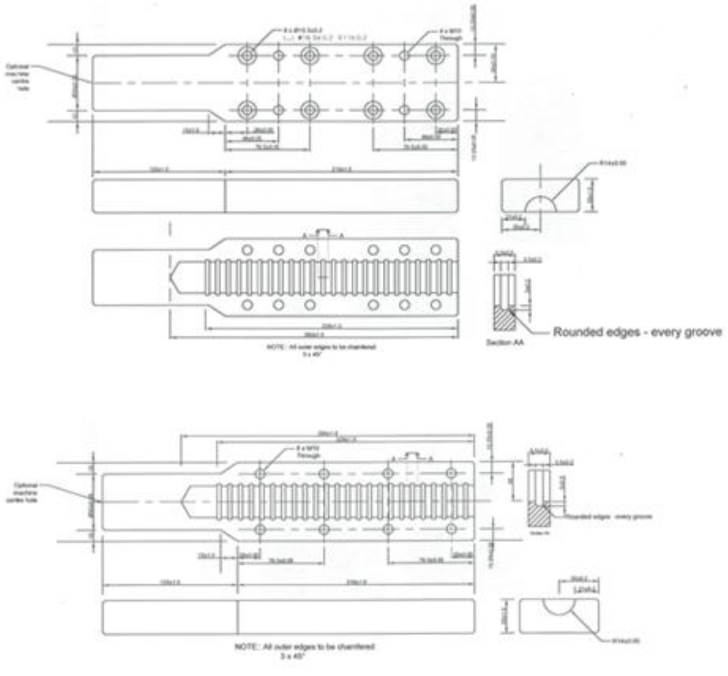

Figure 3. Detailed drawing of Minova axially split SEPT assembly.

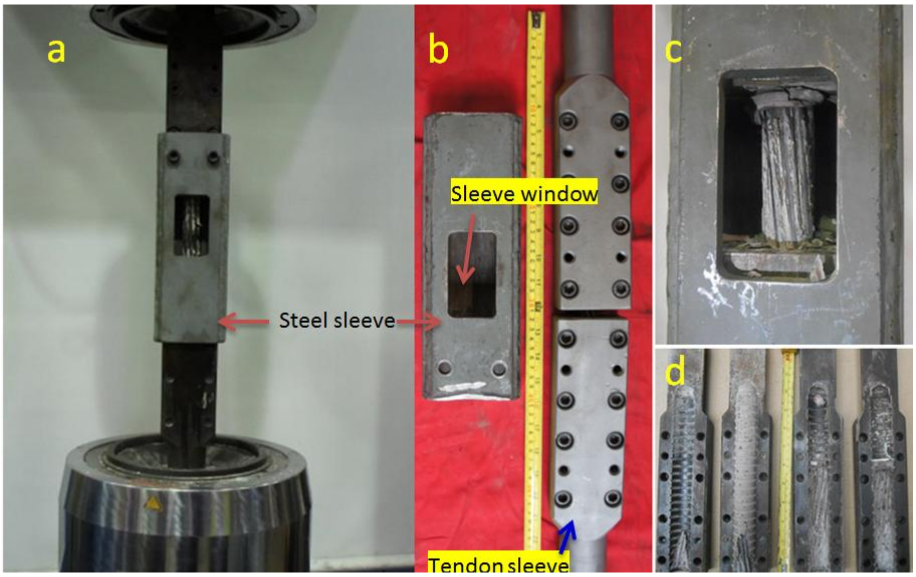

Figure 4. Axially split double embedment pull testing apparatus.

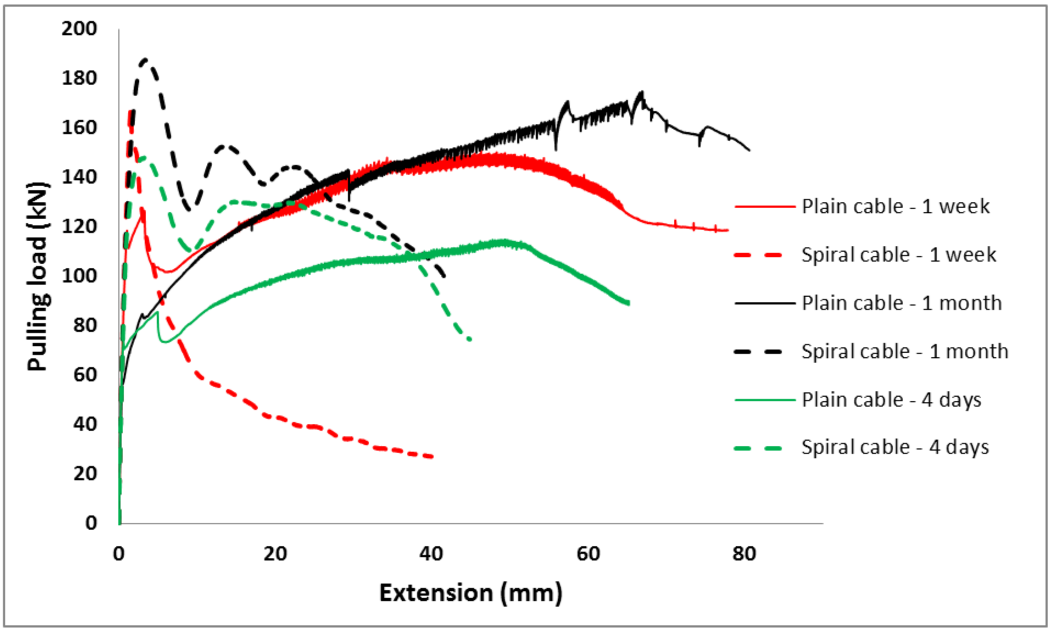

Figure 5. Load-displacement graphs for pull testing of cables at different encapsulating grout ages.

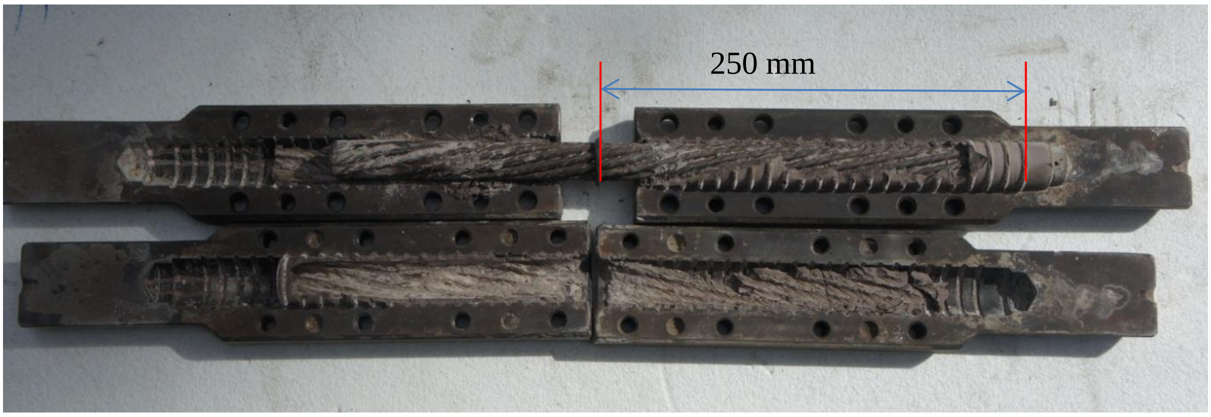

Figure 6. Post-test two halves of pull-out apparatus with encapsulated cable bolt.

Table 1. Pulled out peak load values for 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	168.1	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 followings:

1) The peak load was reached when pulling of all spiral cables occurred at a displacement less than 5 mm. However, the respective peak loads for plain cables were significantly greater.
2) The displacement due to peak load was, in general, higher with spiral wire surfaces.

The profiles of spiral and plain pull loads as well as their respective displacement were in agreement with the load-displacement profiles reported by Thomas (2012) [4], in which, tests were made in sandstone blocks. Addition of the steel sleeve on the pulling apparatus, shown in Figure 4, clearly demonstrates its effectiveness in eliminating cable rotation during pull testing. Also, as expected, the bond strength of the tested samples was noted to increase with the encapsulation grout age. The peak load per mm of the encapsulated plain cable length ranged between 0.676 kN/mm for four day grout, increasing to 1.029 kN/mm for one month old grout, and similarly, for spiral wired cables; the values ranged between 0.87 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 the 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) [4] in sandstone block was 320 mm; and b) the resin used was different from the Minova Mix and Pour resin used in this work. The increased encapsulation age resulted in higher peaks loads.

3) The peak load achieved with plain cable bolts occurred at a greater displacement, irrespective of the grout or resin installation age. The profiles of load displacement are in agreement with the results obtained by Thomas (2012) [4].
4) The use of the steel encapsulation frame allowed repeatability of the tests, faster and economically.
5) The MASEA test apparatus is 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 the Multi-Diameter Laboratory Short Encapsulation Test (MDLSET) apparatus. This instrument will permit the pull-out tests of cables of different diameters.
6) While the use of steel frame may overestimate the bond strength of grout or resin and may not substitute testing of the cables in rocks and in composite material such as concrete, nevertheless, the test results are consistent with the similar results reported by Thomas (2012) [4] in sandstone and steel frame.

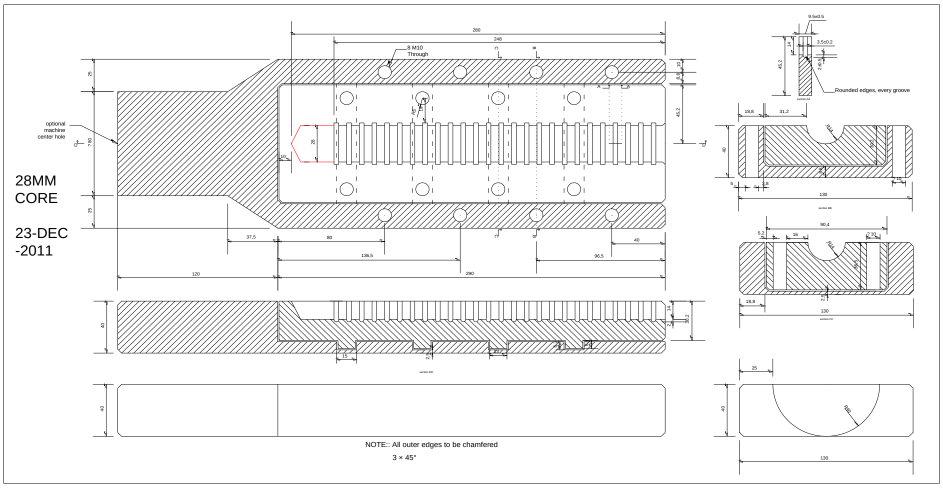

Figure 7. A drawing of multi-diameter laboratory short encapsulation test instrument.

4. Conclusions

A new Minova pull-out instrument was developed for testing cable bolts. It is simple in design and construction. Its main benefit is that it is a fast method that requires no additional testing material other than the resin or grout for cable encapsulation. Using the MLSEPT instrument, it was found that spiral cable pull loads were higher than smooth cables. The peak loads obtained occurred at a shorter displacement in comparison with the smooth cables. Also the peak loads were found to increase with the encapsulation age, irrespective of the cable type.

As part of this work, the current instrument was designed to suit rock bolts and cable bolts of 22-24 mm diameter. The instrument is currently being further developed at the University of Wollongong to study, in details, the effects of cable bolt surface profile on the axial load transfer mechanisms. The modified instrument will permit testing of cables of any diameter and bulbs. This will be achieved by enlarging the system and incorporating separate sleeves of the internal grooves fitted into the outer shelves of the instrument known as MDLSET.

Acknowledgments

The pull testing instrument described in the paper 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 applications. The authors are indeted to Minova for permsion to use this instrument for various testings. The new MDLSET type design system as reported in this paper was developed and proved successful.

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مطالعه آزمایشگاهی مکانیسم انتقال بار محوری پیچ‌سنگ

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چکیده:

مکانیسم انتقال بار در پیچ‌سنگ‌های مختلف با هم تفاوت زیادی دارند. پیچ‌سنگ‌ها اصولاً از رشته‌های فولادی با ساختارهای مختلف با توجه به تعداد رشته‌ها یا اجزای مختلف ساخته می‌شوند. پیچ‌سنگ‌های Tendon خصوصیات مقاومتی و انتقال بارشان مورد ارزیابی قرار می‌گیرند. مقاومت این نوع از پیچ‌سنگ‌ها می‌تواند توسط آزمایش‌های شکست کششی ارزیابی شوند، در حالی که مقاومت انتقال بار توسط آزمایش‌های مقاومت برشی و کششی ارزیابی می‌شوند. آزمایش SEPT معمولاً برای مطالعه ظرفیت انتقال بار پیچ‌سنگ‌ها مورد استفاده قرار می‌گیرند و به صورت برجا و آزمایشگاهی قابلیت کاربرد دارند. در این تحقیق با استفاده از دستگاهی جدید به نام MASEA خصوصیات انتقال بار پیچ‌سنگ‌های مارپیچ مورد مطالعه قرار گرفتند. رزین کپسولی مورد استفاده در این تحقیق دارای طول ۴۰۰ میلی‌متر، قطر ۲۲ میلی‌متر و دارای ۱۹ رشته می‌باشند. مهار پیچ‌سنگ در دو طرف دستگاه در طول‌های مختلف نصب شد تا اجازه داده شود پیچ‌سنگ از یک طرف کشیده شود. رشته‌های سیمی مارپیچی پیچ‌سنگ‌ها در مقایسه با رشته‌های سیمی صاف پیچ‌سنگ‌ها به نقطه ماکزیمم (پیک) رسیدند که این نقطه نیز با افزایش طول عمر رزین افزایش می‌یابد. استفاده از MASEA برای مونتاژ کردن و انجام آزمایش به آسانی انجام می‌شود و بنابراین از طریق این دستگاه می‌توان آزمایش‌هایی سریع و تکرارپذیر را انجام داد.

کلمات کلیدی: مطالعه آزمایشگاهی، بار محوری، پیچ سنگ.