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Parametric study on the axial performance of a fully grouted cable bolt with a new pull-out test

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ABSTRACT

Modified cable bolts are commonly used in underground mines due to their superior performance in preventing bed separation when compared with plain strands. To better test the axial performance of a wide range of cable bolts, a new laboratory short encapsulation pull test (LSEPT) facility was developed. The facility simulates the interaction between cable bolts and surrounding rock mass, using artificial rock cylinders with a diameter of 300 mm in which the cable bolt is grouted. Furthermore, the joint where the load is applied is left unconstrained to allow shear slippage at the cable/grout or grout/rock interface. Based on this apparatus, a series of pull tests were undertaken using the MW9 modified bulb cable bolt. Various parameters including embedment length, test material strength and borehole size were evaluated. It was found that within a limited range of 360 mm, there is a linear relationship between the maximum bearing capacity of the cable bolt and embedment length. Beyond 360 mm, the peak capacity continues to rise but with a much lower slope. When the MW9 cable bolt was grouted in a weak test material, failure always took place along the grout/rock interface. Interestingly, increasing the borehole diameter from 42 to 52 m in weak test material altered the failure mode from grout/rock interface to cable/grout interface and improved the performance in terms of both peak and residual capacity.

1. Introduction

Fully grouted cable bolts have been used in underground mining industry for many decades. Initially, plain cable bolts manufactured by winding seven flexible steel wires together were commonly used [1]. Laboratory and field tests lead to a better understanding of the transfer process between grouted cable bolts and the surrounding rock mass, which is beneficial to improve the reinforcing performance of cable bolts in engineering practice [2–5]. Nevertheless, as in many cases the initial cable was sourced from discarded steel with a smooth surface along the strand, plain cable bolts did not always meet performance expectations [6]. Over time, it was realized that cable surface geometry plays an important role in determining anchorage performance. Consequently, modified forms of cable bolts were developed. For instance, twin-strands which were made by using spacers to combine two plain cables together improved anchorage capacity twofold [7]. However, this required a large borehole to be drilled. Epoxy-coated strands had remarkable performance in practice but were difficult to install without damaging the epoxy layer [8]. In the 1990s, there was a rapid development in the cable bolt design. A typical example was birdcaged cable bolts. They were initially suggested by Hutchins et al. via unwrapping traditional seven-wire strands and generating a number of nodes together with antinodes along the strand [9]. But it was difficult to make birdcaged cable bolts that could be coiled for transporting.

Garford produced bulbed cable bolts by forcing together two parts of one standard strand, causing the wires to separate from each other [10]. Hyett and Bawden found there was a limit to this as extra-large bulb size (more than 40 mm) would lead to poor load transfer behavior [11]. Furthermore, they found the bulb spacing has a significant effect on axial performance. An Ultra strand was proposed by Renwick via assembling metal spacers at a constant interval along the middle wire though again spacer spacing was critical to performance [12]. Hyett et al. reported installation of a hexagonal nut on the middle wire to make nutcaged cable bolts [13]. Mah proposed a cuttable strand manufactured from fiberglass, named as fiberglass cable bolts [14]. Satola pointed out that galvanized strands had pronounced better performance than plain strands [15]. Recently, Tadolini, Tinsley and McDonnell proposed PC-strand tendons by adding regular indentation along peripheral wires [16]. However, it should be mentioned that the indentation geometry has an apparent effect on bearing capacity

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of strands. It can be seen that most of these different types of cable bolts are manufactured based on standard seven-wire strands, which are classified as modified cable bolts.

In the Australian mining industry, the MW9 cable bolts developed by the Megabolt Company are in wide use. This type of modified cable bolts has a nominal diameter of 31 mm and has fully bulbed geometry with a diameter of 36 mm and an average bulb spacing of 500 mm [17]. In order to understand the load transfer performance of MW9 cable bolts, Bigby conducted a series of axial pull tests [18]. However, the testing method used followed a British Standard, using steel pipes to simulate rock mass to confine cable bolts, cited in *Strata Reinforcement Support System Components Used in Coal Mines-Specification for Birdcaged Cable Bolting*. As a consequence, the results obtained are much stiffer than reality. Bigby and Reynolds developed the first LSEPT for flexible tendons, conducting experiments on Mega strands [19]. To be more specific, a biaxial cell was used to provide the confining pressure to a sandstone core sample, creating a constant normal load environment around the installed cable bolt. However, this is not a true reflection of loading surroundings in the field since the underground confining pressure is variable not only along the length of cable bolts but also within the service life of grouted tendons. Considering this problem, Reynolds modified the traditional LSEPT, using a steel shell to restrict the sandstone core, creating a constant normal stiffness circumstance [20]. Similar to that, Thomas selected a split steel tube to serve as the confining medium [21]. Both of those two methods successfully simulated the changeable loading environment around grouted cable bolts. Nevertheless, neither approach has considered the size effect of the sandstone samples on performance of flexible tendons. In consideration of this problem, a new axial test apparatus was developed. Then, various pull-out tests were performed with MW9 cable bolts for better understanding axial performance. Finally, several parameters including embedment length, test material strength, borehole size and so forth were evaluated.

2. Building a new LSEPT apparatus

Generally, axial pull tests on fully grouted cable bolts can be classified as either an unconstrained or constrained test. In unconstrained tests, the cable bolt is likely to rotate due to their special helical surface geometry, resulting in a much poor pulling response [22]. Based on this consideration, it is necessary to build a non-rotating test rig. A new LSEPT apparatus was designed and constructed in the School of Mining Engineering, UNSW Australia, which is depicted in Fig. 1. This equipment is composed of two main parts, which are the embedment section and anchor segment.

2.1. Embedment section

The lower part or the embedment section is the most important part of this new test rig. Usually, a sandstone core with a diameter of 142 mm is used to confine the grouted cable bolt. However, a recent study by Holden and Hagan found the size of test sample has a direct effect on the bearing capacity of a cable bolt [23]. In order to determine the appropriate size of test sample for the new cable bolt testing facility, two series of pull-out tests were conducted using a Sumo strand cable bolt. This is a high capacity modified cable bolt with similar characteristics to the MW9 cable bolt. This entailed the Sumo strand bolts being were pulled from test samples ranging in diameter from 150 to 500 mm. Detailed information regarding the sample preparation and pull-out process has been described by Chen et al. [24]. After testing, a bi-linear relationship was found between the bond strength or the peak capacity and sample size, as shown in Fig. 2. With sample diameters less than 350 mm there was a linear increase in bond strength with diameter but beyond 350 mm the bond strength was effectively independent of test sample size that is the size of test sample no longer has any influence on the performance of the cable bolt. Rajaie reported a similar result in testing a plain strand cable [25]. In that case the inflection point was only 200 mm, this smal-

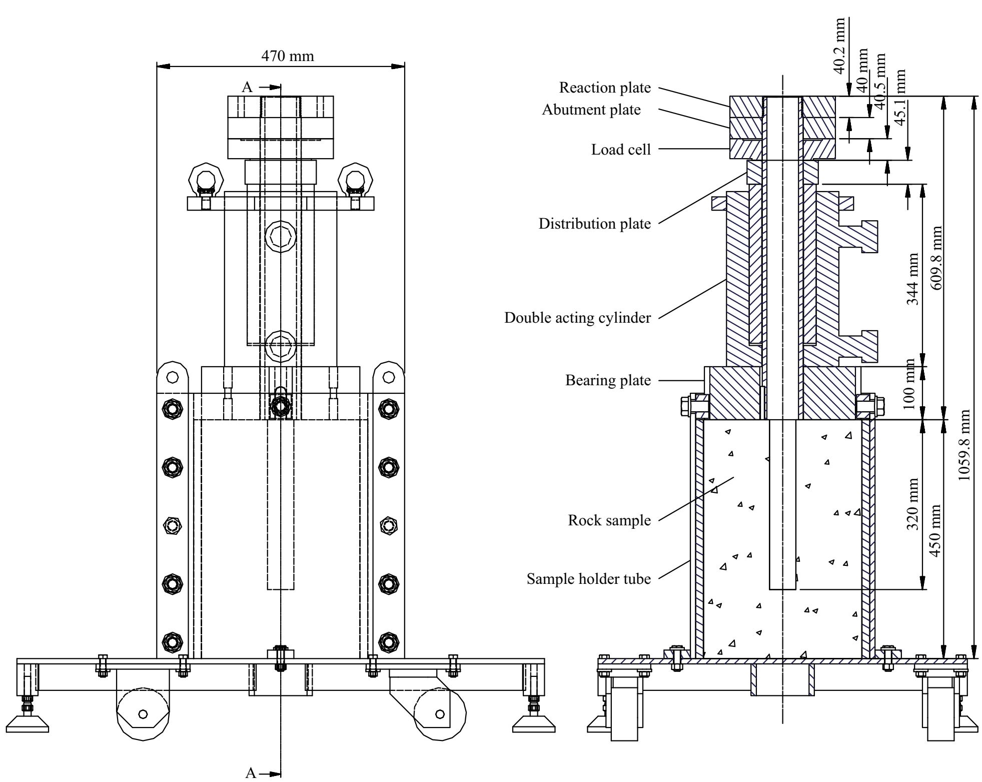

Fig. 1. Front and side views showing dimensions of the various components of the new testing facility.