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Sample diameter effect on bonding capacity of fully grouted cable bolts

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ABSTRACT

Bonding capacity of cable bolts plays a significant role in determining the load transfer performance of fully grouted cable bolting systems. Bonding capacity can be assessed with laboratory scale tests on cable bolts grouted in rock-like samples. A number of pull-out tests were conducted using a bulbed cable bolt to investigate the cylindrical sample diameter effect on the bonding capacity. A cement-based material was used to prepare the samples having various diameters. Two different boundary conditions were examined, where the cylindrical sample was unconfined and confined within a stiff steel tube. The results show that the bonding capacity increased linearly with sample diameter up to 356 mm in the unconfined condition. In the confined condition, however, the threshold reached at a low diameter of 300 mm. Furthermore, it was found that the bonding capacity in the confined condition was always higher than in the unconfined condition. The failure mode of the cable bolting system was also influenced by the boundary conditions. In the unconfined condition, it was observed that the sample was likely to split. Whereas in the confined condition, performance of cable bolts was mainly dominated by the bonding failure.

1. Introduction

The stability of underground excavations is of great importance in both civil and mining activities (Cai et al., 2004; Li et al., 2016). To increase the integrity of rock mass around openings, fully grouted cable bolts are commonly used. Numerous laboratory and field tests have demonstrated that cable bolts are effective in improving the inherent shear strength of rock mass (Kaiser et al., 1992; Hyett et al., 1995; Barley and Windsor, 2000; Singh et al., 2001; Moosavi and Grayeli, 2006; Ren et al., 2010; Chen et al., 2015; Chen et al., 2016; Li et al., 2017). Nevertheless, failure of cable bolting systems, especially bonding failure can present a problem caused by insufficient interfacial bonding capacity.

The bonding capacity of cable bolts is usually indicated by the maximum pull-out load (Fuller and Cox, 1975; Cox and Fuller, 1977; Hutchinson and Diederichs, 1996). To study the bonding capacity of cable bolts, a number of research has been conducted. The most commonly used method is pulling cable bolts from cylindrical samples made up of cement-based or concrete materials.

Stillborg (1984) used concrete materials to cast cylindrical samples with a diameter of 300 mm and conducted pull-out tests on plain cable bolts. His results showed that the greasy substance coated on plain cable bolts had a negative effect on the bonding capacity of cable bolts and recommended that the cable bolt surface should be kept clean before installation. Farah and Aref (1986a) also conducted pull-out tests on plain cable bolts installed in cylindrical blocks. Two different block diameters, 150 mm and 250 mm, were used. They found that cable bolts grouted with concrete materials had larger bonding capacity than those grouted with plain cement. Hassani and Rajaie (1990) used concrete blocks with a diameter of 250 mm to confine cable bolts and studied the effect of grout materials on the bonding capacity of cable bolts. The results showed that compared with the plain cement grout, the aggregate-cement grout can improve the peak and residual bonding capacity of cable bolts. Benmokrane et al. (1995) conducted pull-out tests on plain cable bolts installed in samples with a diameter of 200 mm, finding that the cable surface geometry and grout had a significant effect on the bonding capacity of cable bolts, especially when large displacement occurred. Altounyan and Clifford (2001) used a different material, namely sandstone to confine cable bolts and conducted pull-out tests. The diameter of samples is 142 mm. Testing results showed that pre-tension can effective improve the performance of cable bolts. The same test approach was also used by Bigby (2004), who found that the cable geometry had a significant effect on the stiffness of the cable bolting system. Blanco Martín (2012) developed a laboratory short encapsulation pull test for rock tendons and conducted pull-out tests on plain cable bolts. The sandstone samples with a diameter of 142 mm were used. Test results showed that plain cable bolts can maintain a high bonding capacity to a large displacement of 60 mm in

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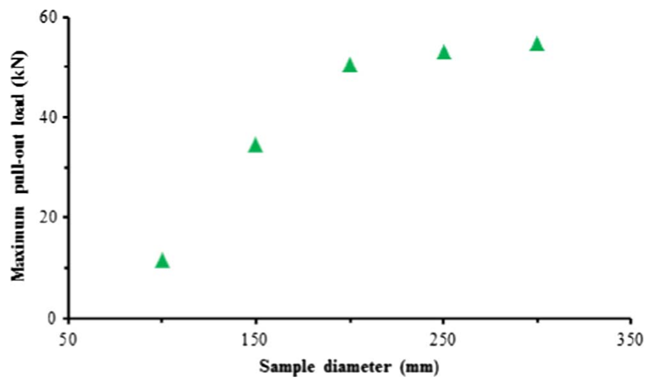

Fig. 1. Sample diameter effect on the performance of plain cable bolts (after Rajaie, 1990).

pull-out tests.

According to the literature review, the effect of different parameters such as cable surface geometry, grout quality and coating materials on the bonding capacity of cable bolts has been studied. However, a common problem occurring in those tests is that the sample diameter is largely different. This is due to the fact that there is no common test standard in requiring the samples' diameter and the variation in sample diameter made it difficult to compare previous test results.

In fact, little research has been conducted to evaluate the sample diameter effect on the bonding capacity of cable bolts. The pioneering work was conducted by Rajaie (1990), who evaluated the sample diameter effect on the pull-out performance of plain cable bolts. Specifically, he used concrete materials to cast samples with the diameter ranging from 100 mm to 300 mm. The test results showed that when the sample diameter is smaller than 200 mm, the bonding capacity of cable bolts apparently increased. However, once the sample diameter is larger than 250 mm, the bonding capacity became stable, as shown in Fig. 1. Therefore, he concluded that the sample diameter had a direct effect on pull-out performance of cable bolts and recommended that when pulling a cable bolt from the sample, the sample's diameter should be large enough. However, his results are only applicable to plain cable bolts.

Holden and Hagan (2014) used same approach to test the sample diameter effect on a bulbed cable bolt. Four different sample diameters ranging from 150 mm to 450 mm were used. It was found that there is a linear relationship between the bonding capacity and sample diameter. However, during the test, no confinement was provided on the sample.

The sample diameter effect on the bonding capacity of cable bolts has not been fully understood. Furthermore, no research has been conducted in evaluating the sample diameter effect on bulbed cable bolts in the confined condition.

Therefore, this paper aims at studying the sample diameter effect on the bonding capacity of a bulbed cable bolt. The single embedment pull-out test method was used. Because first, it is the most commonly used method to test the performance of cable bolts (Stillborg, 1984; Farah and Aref, 1986b; Farah and Aref, 1986a; Hassani and Rajaie, 1990; Benmokrane et al., 1992; Benmokrane et al., 1995; Altounyan and Clifford, 2001; Tadolini et al., 2012; Holden and Hagan, 2014). Second, Rajaie (1990) conducted the pioneering work to study the sample diameter effect on cable bolts and he used the single embedment pull-out test. Following his work, the single embedment pull-out test method was also used in this study. This makes it possible to compare test results with Rajaie (1990)'s results.

In this paper, first, the pull-out test design was depicted. Then, a number of pull-out tests were conducted using a bulbed cable bolt. After that, the pull-out test results were compared. The effect of sample diameter and boundary condition on the bonding capacity of cable bolts was also analysed.

2. Experimental program

Two series of pull-out tests were performed using a high capacity bulbed cable bolt with different boundary conditions. In the first series of tests, samples were left in an unconfined state, while in the second series of tests, the samples were placed in a steel cylinder to be tested in confined state.

2.1. Tests under unconfined condition

All samples were cast in cylindrical cardboard moulds having a height of 320 mm and diameters ranging from 150 mm to 508 mm. Rajaie (1990) recommended that the sample diameter should be larger than 250 mm in the unconfined condition. Following his recommendation, in this research, most tested sample diameters including 254 mm, 300 mm, 356 mm and 508 mm were larger than 250 mm. However, to add a reference, a diameter of 150 mm was still tested.

In the centre of each mould, a PVC pipe having an outside diameter of 42 mm was placed to represent the borehole. A plastic wire with a thickness of 3 mm was wrapped around the PVC pipe at an interval of 35 mm. This was done to simulate a consistent rifled borehole, increasing the borehole roughness and mechanical interlock between the grout and test sample. A set of prepared casting moulds is shown in Fig. 2.

To be consistent with the sample strength used by Rajaie (1990), cement-based materials with the uniaxial compressive strength (UCS) of 30 MPa were poured into the moulds. After setting for 24 h, the cardboard mould, PVC pipe and plastic wire were removed. All samples were then fully immersed in a water basin, for curing for 28 days. The boreholes were then backfilled with a cement-based material to create a constant borehole length of 280 mm. The sample and rifling borehole effect are shown in Fig. 3.

The SUMO cable bolt, which is a new bulbed cable bolt design, manufactured by the Jennmar Australia, having the largest load transfer capacity was tested in this study. Thus, the results acquired can also be applicable to other cable bolts having lower load transfer capacity. This cable bolt has a diameter of 28.5 mm and a bulbed section with a diameter of 35 mm. The full length of the SUMO cable tested is 900 mm, in which the left section of 280 mm (Fig. 4) was fully embedded in the borehole of the test sample.

A polyester resin grout was used to bond the cable bolt in the test sample. The resin grout was first poured into the borehole. Then the cable bolt was installed and rotated to ensure a full contact between the bolt, resin grout and specimen. After the resin grout cured for further 2 days, the samples were ready for testing, as shown in Fig. 5.

The approach of single embedment pull test was adopted. A bearing

Fig. 2. Cardboard moulds with the internal diameters ranging from 150 mm to 508 mm.