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# Shear strength properties of cable bolts using a new double shear instrument, experimental study, and numerical simulation

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ABSTRACT

A newly developed double shear apparatus without contact between concrete blocks was developed to conduct a series of double shear tests. This new double shear apparatus is capable of determining the pure shear strength of pre-tensioned fully grouted cable bolt without friction between sheared concrete blocks. Five different types of cable bolt, with various pretension loads, were tested to investigate the influence of surface profile type and pretension load on the shear strength of cable bolt. Concrete blocks of 40 MPa strength and the Stratabinder HS grout were used for consistency across the entire tests. The results showed that the plain cable bolts had higher peak shear load compared with the indented and spiral strand cable bolts. The shear displacement and peak shear load decreased by increasing the pretension load. A numerical analysis was carried out, based on the Fast Lagrangian Analysis of Continua (FLAC 2D) and the result was compared with the experimental data. It was observed that FLAC 2D is capable of simulating the performance of cable bolt satisfactorily.

## 1. Introduction

The application of cable bolts as a secondary support system in underground coal mines and tunnelling is on the increase worldwide since their introduction in 1960s (Fuller and O'Grady, 1993). The difference between then cable bolt and rock bolt is that the cable bolt is a flexible tendon with high tensile strength to allow rock mass to support itself (Hutchinson and Diederichs, 1996; Windsor, 1992; Fuller, 1983; Puhakka, 1997). The plain strand cables with poor load transfer properties were the first type introduced to mines. Thus, they were only used as a temporary means of rock reinforcement support particularly in metal mines. Over the years, a number of modifications was made to cable strand, such as strands surface profiling and indentations (Schmuck, 1979), the double plain strand (Matthews et al., 1983), the epoxy-coated strand (Dorsten, 1984), the fiberglass cable bolt (Mah, 1994), the birdcaged strand (Hutchins et al., 1990), the bulbed strand (Garford, 1990), and the nutcaged strand cable bolts (Hyett et al., 1992). These different types of modifications have been incorporated to various cable types to improve their load transfer capacity for effective ground reinforcement support.

There are different mechanisms of cable bolt failures; axial, shear or the combination of axial and shear failures. In reality, failures of cable bolts are a combination of axial and shear. Cao (2012) described that the axial failure in cable bolt depends mostly on the strength and characteristics of cable bolt, rather than the strength of grout and rock mass. The cable bolt failure occurs when the optimum required support will be higher than the strength of the cable bolt. Due to the smaller effective area, the shear strength in the bolt-grout interface is different from the grout-rock interface. The strength or weakness of bonding between the grout and cable varies depending on the strand wires surface roughness and cleanness. There are different methodologies available to evaluate the performance of cable bolt, which include pull out and shear tests.

Many studies have been undertaken over the years by researchers using pull testing to determine the tensile failure and load transfer capacity of cable bolts and rock bolts (Hawkes and Evans, 1951; Fuller and Cox 1975, 1978; Goris, 1990; Yazici and Kaiser, 1992; Hyett et al., 1992; Diederichs et al., 1993; Bouteldja, 2000; Clifford et al., 2001; Morsy et al., 2004; Thomas, 2012; Chen et al., 2016).

Dulacska (1972) conducted 15 single shear tests by using various concrete grades, three steel sizes and four different angles for stirrup to evaluate dowel action in the cracked concrete. Spang and Egger (1990) studied the performance of fully grouted un-tensioned bolts in the jointed rock mass subjected to the single shear test. Two different angles between joint surface and bolt (30° and 90°) were studied. Ferrero (1995) conducted a series of single shear test on weak and strong rocks

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**Table 1**
Double shear test of various cables without concrete blocks' friction (MKIII) and cable bolts' properties.

| Test no. | Cable | Wire strand no. | Cable dia. (mm) | UTS (t) | Elongation at strand failure (%) | Lay length (mm) | Hole dia. (mm) | Pt (kN) |
|---|---|---|---|---|---|---|---|---|
| 1 | Plain 19 wires[a] | 19 | 21.7 | 60 | – | 300 | 36 | 0 |
| 2 | Plain 19 wires[a] | 19 | 21.7 | 60 | – | 300 | 36 | 160 |
| 3 | Plain 19 wires[a] | 19 | 21.7 | 60 | – | 300 | 36 | 100 |
| 4 | Plain 19 wires[a] | 19 | 21.7 | 60 | – | 300 | 36 | 0 |
| 5 | Plain SUMO | 9 | 28 | 65 | 5–7 | 400 | 42 | 0 |
| 6 | Plain SUMO | 9 | 28 | 65 | 5–7 | 400 | 42 | 150 |
| 7 | Indented SUMO | 9 | 28 | 63 | 5–7 | 400 | 42 | 0 |
| 8 | Indented SUMO | 9 | 28 | 63 | 5–7 | 400 | 42 | 150 |
| 9 | Plain MW10 | 10 | 31 | 70 | 5–6 | 600 | 42 | 0 |
| 10 | Plain MW10 | 10 | 31 | 70 | 5–6 | 600 | 42 | 150 |
| 11 | Spiral MW9 | 9 | 31 | 62 | 5–6 | 600 | 42 | 0 |
| 12 | Spiral MW9 | 9 | 31 | 62 | 5–6 | 600 | 42 | 75 |
| 13 | Spiral MW9 | 9 | 31 | 62 | 5–6 | 600 | 42 | 150 |

NB: Pt: Cable bolt pretension load; Concrete blocks with 40 MPa strength and Stratabinder HS grout for encapsulation were used.
[a] 19 wire (9 × 9 × 1) twin layer seal construction cable strand.

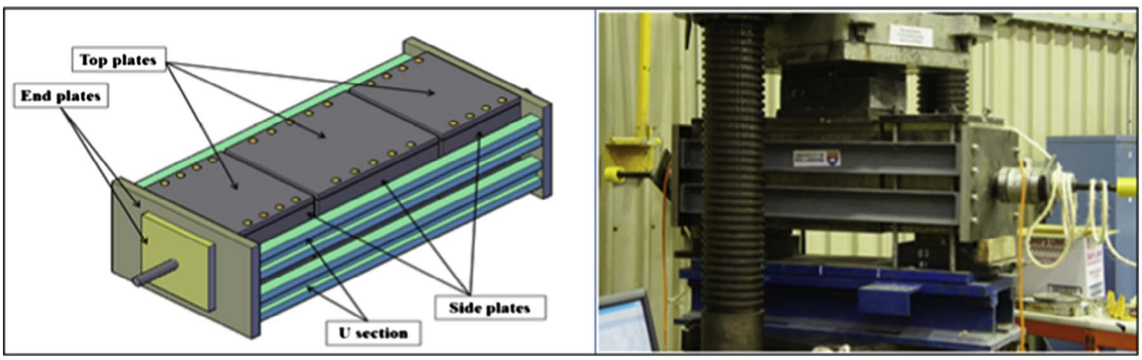


**Fig. 1.** Double shear assembly MKIII without friction between concrete blocks.

**Table 2**
Maximum deflection in the end plate with different thicknesses.

| Thickness (m) | b (m) | I ($m^4$) | $\delta$ (m) |
|---|---|---|---|
| 0.03 | 0.32 | 7.2E−07 | 6.1 |
| 0.04 | 0.32 | 1.71E−06 | 2.57 |

**Table 3**
New double shear test assembly dimension size.

| Plate's location | Dimension ($mm^3$) | Number |
|---|---|---|
| Bottom | 340 * 300 * 20 | 2 |
| Bottom | 340 * 450 * 20 | 1 |
| Side | 300 * 300 * 20 | 4 |
| Side | 450 * 300 * 20 | 2 |
| Back | 520 * 350 * 30 | 2 |
| Connection | 150 * 100 * 40 | 8 |
| U section | 100 * 40 | 4 |

and developed a mathematical model to evaluate the shear strength of rock bolts. Pellet and Egger (1996) used the energy balance theory to evaluate the performance of un-tensioned fully grouted rock bolts and developed an analytical model to determine the contribution of rock bolt to the shear strength of rock joints. Haas (1976) studied the effect of pre-tension load and rock bolt orientation to the sheared surface (0°, +45° and −45°) by conducting a series of single shear test on rock bolts installed in chalk and limestone blocks. Fuller and Cox (1978) determined the angle of cable bolt to a joint discontinuity as 30° for generating tension in the cable bolt upon shearing. Bjurstrom (1974) investigated that the bolt failure occurs in tension when the angle between the rock bolt and the shear plane is 35°. Windsor and Thompson (1994) used single shear testing apparatus on fully grouted cable bolts to determine the best angle of installation of the cable bolt to the shear joint. Results show that the shear resistance of the cable bolt with the angle of 45° to the discontinuity is much greater than to 90°. Also, Azuar (1977) and Ge and Liu (1988) discussed the effect of the bolt angle to the rock joint on the shear strength of the bolted rock joint, however Hibino and Motojima (1981) stated that the angle of bolt installation does not affect the shear strength of the system. Stillborg (1984) studied the shear performance of fully grouted cable bolts using the single shear test methodology. The shear strength of the grouted cable bolt was considerably less when the angle of cable to the joint surface was 90° compared with 45°. The single shear apparatus as suggested by British Standard BS7861-2 (2009) has been introduced to determine the shear strength of cable bolts. This single shear instrument is a guillotine box type to shear the encapsulated cable bolt positioned in a cylindrical steel frame. The method tends to underestimate the shear strength of the cable, because the outer steel pipe literally cuts into the cable bolt wires at a short vertical shearing displacement due to a limited thickness of annulus encapsulation grout as reported by (Aziz et al., 2015d). Accordingly, the double shear method was proposed as a more effective alternative (Aziz et al., 2016a,b; Rasekh et al., 2015).

In Australia, Aziz et al. (2003) studied the shear performance of fully grouted rock bolts with three common types of rock bolts and concrete blocks with the strength of 20 and 40 MPa using small scale double shear assembly (MKI). The system stiffness increased with higher strength concrete blocks. Aziz et al. (2005) measured the effect of resin thickness on the load transfer capacity from bolt to the concrete blocks. It was concluded that by increasing the resin thickness, the load transfer capacity of the rock bolt subjected to axial loading (pulling or pushing) decreased. Also, the shear load resistance was found to be more dependent on the concrete blocks strength rather than the resin thickness. Grasselli (2005) studied the un-tensioned fully grouted rebar and Swellex bolts subjected to double shear tests with unconfined