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AN EXPERIMENTAL STUDY ON THE CONTACT SURFACE AREA OF CABLED BOLTED STRATA

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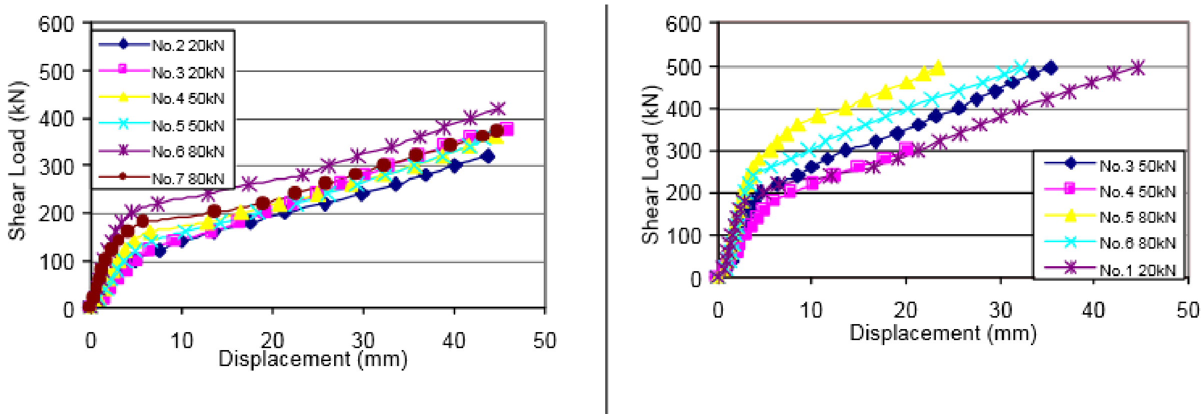
ABSTRACT: The application of cable bolts in underground mines is an increasing trend all over the world; therefore, it is necessary to determine the axial and shear stresses on cable bolts. One important factor is to determine the coefficient of friction of concrete joint surface. This paper examines the contact coefficient of several cabled strata under various pre-tension loads subject to double shearing test. The result shows that the contact surface area can vary between 70-90% of the total surface area. This empirical value helps to figure out shear and axial stresses, where it is impossible to determine the exact amount of contact coefficient.

INTRODUCTION

Cable bolts, as a secondary support system in the mining industry, have been used since the 1960s (Fuller and O'Grady, 1993). The cable bolt provides reinforcement for the bed rock to support it-self. There are different methodologies to determine the behaviour of cable bolts, which are pull out tests and shear tests. Hawkes and Evans (1951), Fuller *et al.,* (1978), Diederichs (1993), Bouteldja (2000), and Yassein (2004) reported the strength of cable bolts for evaluating the tensile failure and load transfer capacity by using the pull test methodology. Nowadays, the performance of cable bolts under shearing is a topic of interest which can be conducted in the laboratory by using either the single shear or double shear tests. Generally, cable bolt failure in the field is a combination of shear and tensile loading. The single shear test as an approach to determine the shear performance of cable bolts has been conducted by a large number of researchers although double shear tests simulate the field condition in a better way. Aziz, *et al.,* (2003) conducted 28 double shear tests on three common types of bolt in Australia with concrete block strengths of 20MPa and 40MPa. The strength of concrete contributed to increase in load transfer capacity of the bolt for the given axial pre-tension load and the value of system stiffness was higher for higher strength concrete (see Figure 1).



(a) Bolt Type 1 in 20 MPa Concrete (b) Bolt Type 1 in 40 MPa Concrete

Figure 1: Effect of concrete type in the peak shear load of different rock bolts

Aziz, *et al.,* (2005) investigated the effect of resin thickness in shear for bolt-grout-concrete interaction by double shear testing. Two types of concrete blocks with different strength of 20 MPa and 40 MPa were used for the tests and the study was further reinforced with ANSYS numerical simulation. The results show that the thickness of resin is an important factor in transferring load from bolt to concrete. Increasing the thickness of resin reduces the load transfer capacity, when the bolt was axially loaded (pulling or pushing). The result from the numerical model was in agreement with the experimental

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results. The shear resistance and shear displacement are more influenced by the strength of concrete block when compared to the resin thickness (Figure 2). Grasselli (2005) carried out a series of double shearing tests on two different types of bolt; fully grouted solid bolt and Swellex bolts. The numerical study was carried out using three-dimensional Finite Element (FEM) code. The experimental curve for both bolt types had three similar steps, but the ultimate contribution to the shear resistance for the steel bar was rather higher than for that of the hollow Swellex bolt. The study by Jalalifar (2006) shows the effect of pre-tensioning on the maximum tensile load as shown in Figure 3. Craig and Aziz (2010) conducted two double shear tests on the 28 mm hollow strand "TG" cable bolt. The initial pre-tensioning were 50 kN and 90 kN and the maximum permitted shear displacement were 50 mm and 75 mm respectively. The increase in the initial pre-tension load contributed to increased shear load at reduced shear displacement, which is evident in Figure 1. Aziz *et al.,* (2014 a) carried out double shearing tests on the 19 wire HTT-IXG Hilti plain and indented cable bolts to study their performance. It was found that the maximum shear load and axial load for the plain cable was higher compared to the indented one while the vertical displacement was lower for the plain cable compared to the indented cable. The result of the tensile test of the single strand shows that the strength of indented strand was also 10% less than the plain one. Aziz *et al.,* (2014 b) studied the series of double shear test on the fibre glass cable bolts. The result of this study highlighted the impact of pre-tensioning and grout type on the peak shear load.

This paper is aimed at identifying the amount of the applied force required to overcome the shear generated across the joint faces as a component of the overall force required for double shear testing.

SHEAR FORCE COMPONENETS

In double shear testing of a reinforcement element installed in concrete, the applied shear force is consumed in overcoming the shear resistance of both the reinforcement element and shear joint surface. The shearing load applied is consumed in;

a) Shearing and bending of the cable bolt, and
b) Overcoming the shearing friction of the two concrete joint faces
c) Shearing of the grout annulus which is small and can be considered as part of the concrete joint faces.

Thus, it is imperative that the above three shearing components be quantified so that their or near realistic force values can be determined. This can be achieved by either;

1. Determination of the shear strength of concrete blocks joint surfaces, which can be deducted from the total shear strength to calculate the shear strength of cable bolt, or
2. Eliminate completely the effect of shearing concrete faces by leaving small gaps between concrete blocks to neglect the contact resistance between concrete blocks. By this method, the total shear strength is the strength of cable bolt.

The focus of this paper is on the first method, while the second method represents an alternative approach, which can realistically determine the contribution quantities from that due to concrete and grout.

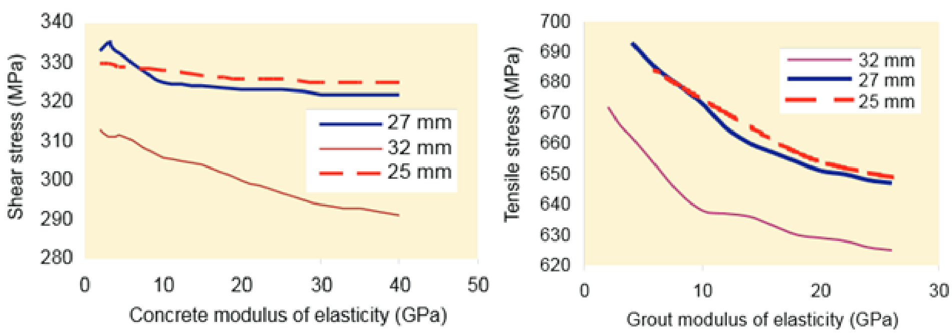

Figure 2: Induced shear and tensile stresses versus grout modulus of elasticity in, left: different resin thickness, right: soft concrete Aziz *et al.*, (2005)

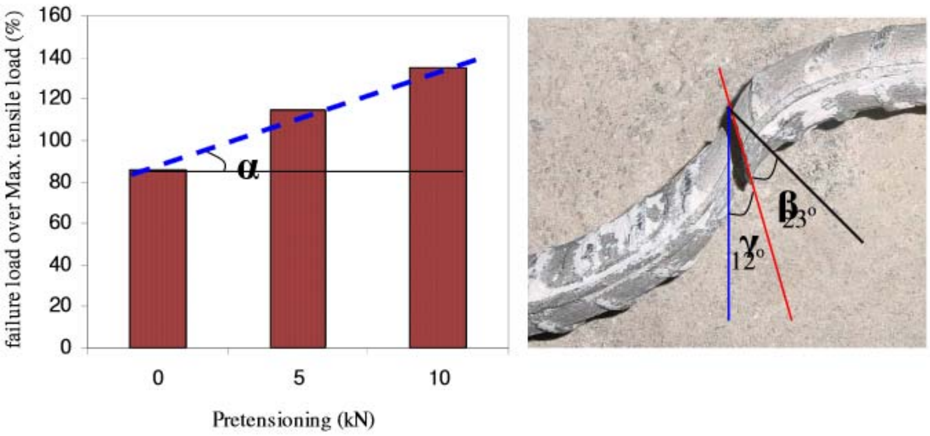

Figure 3: Effect of pre-tensioning on the maximum tensile load (Jalalifar 2006)

Several uncertain factors remain in the double shear test for the first method, such as the contact coefficient of concrete blocks. This factor is an important factor in calculating the shear and axial stresses of the cable bolts using the shear and axial loads according a series of tests were undertaken to evaluate and quantify the coefficient factors under different test conditions.

TEST APPARATUS, SAMPLE PREPARATION, AND EXPERIMENTAL PLAN

The double shear assembly consisted of three concrete blocks with cross sectional area of 300 x 300 mm^2 while the outer concrete blocks length was 300 mm and the middle one was 450 mm (see Figure 4). The concrete blocks had a compressive strength of 40 MPa. They were cast in the steel frame of the double shear apparatus while a 20 mm thick plastic conduit was positioned through the mould for cable bolt installation. The concrete blocks were kept wet for 28 days for curing purposes.

Subsequently, the surfaces of concrete blocks were painted using special painting pattern shown in Figure 5. Each surface was divided to 36 squares that helped to precisely determine the contact surface area after the test. Then, the concrete blocks were mounted in the steel moulds. In order to monitor the axial loads generated on the cable bolt during pre-tensioning and shearing test, two 60 t load cells were incorporated. The cable bolt was retained in tension by installation of two sets of barrels and wedge. After pre-tensioning the cable bolt, chemical resin or cementitious grouts were injected to the holes on top of the concrete blocks depending on the test requirements, and tests were conducted seven days later. The 500 t machine at the rock mechanics laboratory of University of Wollongong was used to perform the double shear tests. Figure 6 shows the installed cabled bolt in double shear test assembly in the 500 t machine. The rate of shear displacement was set by the digital controller. The shear load was applied to the sample using a hydraulic jack located on top of the instrument. The middle concrete block was moved in a vertical direction. The amount of shear and normal load and shear displacement were recorded by the data taker.

Figure 4: Concrete block dimensions

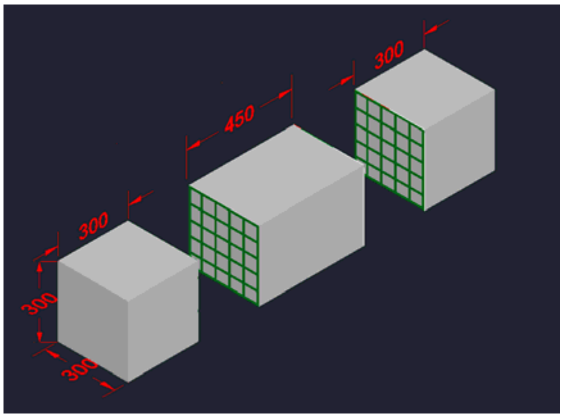

Figure 5: Concrete block painting

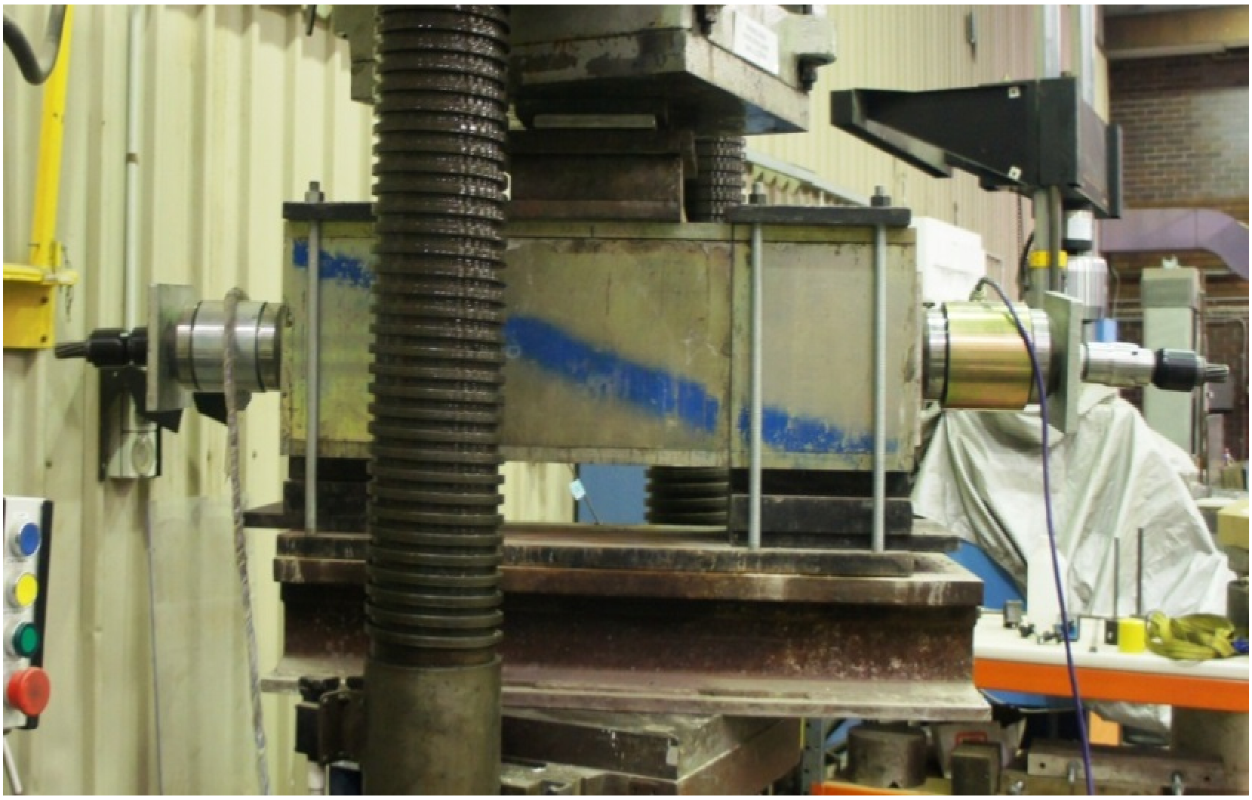

Figure 6: Arrangement of shearing apparatus in compression machine

More than 10 double shear tests were conducted on various samples. The value of initial normal load varied between 0, 100 and 250 kN while the rate of shear displacement was set to 1 mm/min. The first test was conducted without installing cable bolts in the concrete block and the purpose was to investigate the pure shear strength of concrete blocks. Seven different types of cable bolts were tested with different type of grout and pre-tension loads as shown in Figure 7 and Table 1.

TEST RESULTS AND DISCUSSION

The aim of this research was to determine the pure shear strength of cable bolts; therefore, it was essential to calculate the shear strength of the concrete blocks joint surfces at the desired value of the applied axial stress. Figure 8 shows the relationship between the normal and shear stresses for the sliding concrete blocks. By using the Mohr Coulomb equation, the friction angle was drawn as 26.94°. The cable bolt shear strength, can then be obtained by deducting the shear strength of concrete block joints surfece from the total shear strength obtained from shearing test.

Figure 9 shows the concrete blocks after shearing. As previously mentioned, each surface was divided into 36 squares. The Contact Coefficient (CC) was calculated as:

$$CC = \frac{Number\ of\ damaged\ squares}{Total\ square\ numbers\ (=36)} \times 100 \qquad (1)$$

The amount of CC for experimental tests of this study are summarised in Table 2. The average of CC of the cabled concrete, after shearing, was 80% of the total area. This value can be considered between 70% and 90% where it is impossible to determine the contact coefficient of concrete blocks precisely.

Then, the axial stress and shear stress can be calculated using the following equations:

$$\sigma_n = \frac{N}{CA} \qquad (2a)$$

$$\tau = \frac{0.9 \times S}{2 \times CA} \qquad (2b)$$

where, σ_n is the normal stress, *N* is the normal load, *S* is the shear load and CA is cable area.

The damage on the concrete blocks was mostly concentrated around cable bolts. It was noted that by increasing pre-tensioning, the contact coefficient increases. The reason is that the load applied to the concrete blocks and cable bolt subjected the sheared concrete joint faces tight and increased the contact forces between concrete blocks. This is evident in tests 5 and 7 and also in tests 7 and 8. For instance, CC values for the Indented SUMO-Hollow 28mm cable with pre-tensioning forces of 10 t and 25 t, the CC values were 75% and 81% respectively. The stiffness of cable is more compared to the concrete block, and this is the reason why the cable bolt carries 90% of the total shear load. Table 2 shows the total shear strength and the pure shear strength of cable bolts. The result from this method of testing is approximately and hence required a closer look. Figure 10 shows an alternative approach to eliminate the effect of the Joint surfaces shear values. The new design of the double shear apparatus should prevent shearing joint faces coming in contact with each other, thus the applied shear load will enable accurate determination of the cable bolt shear strength.

Figure 7: Cable bolts used for double shearing test purpose

Table 3: Detail of double shear tests carried out on various cables with different pretension loads and grouts

Test No.	Cable Bolt Properties					Drill bit (mm)	Bonding agent	Pre-tension load (t)	Peak shear load (kN) [½ double shear]
	Product name	Cable ø (mm)	Wire geometry	Cable cross-section	Cable geometry				
1	Indented Superstrand	21.8	Indented	19 wire, PC strand	Non-birdcaged	28	Oil based resin	25	558
2	Superstrand	21.8	Plain	19 wire, PC strand	Non-birdcaged	28	Oil based resin	25	628
3	Indented TG	28	Indented	9 wires, hollow centre	Non-birdcaged	42	TD80 Grout	25	604
4	Indented SUMO	28	Indented	9 wires, hollow centre	35mm birdcage	42	TD80 Grout	25	414
5	Indented SUMO	28	Indented	9 wires, hollow centre	35mm birdcage	42	TD80 Grout	10	488
6	Plain SUMO	28	Plain	9 wires, hollow centre	35mm birdcage	42	TD80 Grout	25	711
7	Plain SUMO	28	Plain	9 wires, hollow centre	35mm birdcage	42	TD80 Grout	10	659
8	Gardford twin-strand	15.2	Plain	2 x 7 wire, PC strand	25mm Bulbs	55	BU100 Grout	0	501
9	Orica Secura HGC cable	30	Plain & indented	5 plain wire +4 indented wire	Non-birdcaged	42	FB400	25	800.5
10	Orica Secura HGC cable	30	Plain & indented	5 plain wire +4 indented wire	Non-birdcaged	42	Carbothix resin	10	772

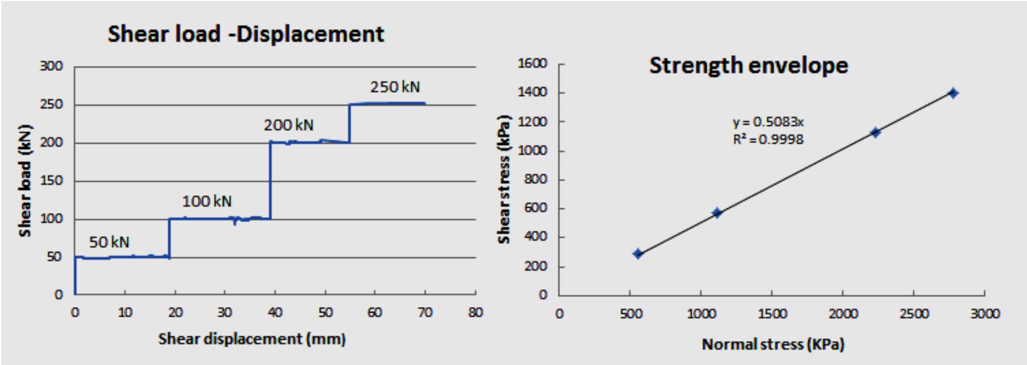

Figure 8: test results of the concrete blocks sliding test

CONCLUSION

- Testing of cable bolts in concrete represent a realistic away of simulating shear failures in rocks in underground.
- There is a significant level of shear force spent in overcoming the sheared concrete joint surfaces friction. The level of forces is rather difficult to quantify accurately by using CC by the painted pattern damage. One approach will be the elimination of the joint surfaces coming in contact with each other during shearing. Also, by increasing the pre-tensioning leads to increase in the contact coefficient.

Table 2: Peak shear strength for different cabled concrete blocks

Test Number	Contact coefficient (%)	Total Shear strength (GPa)	Shear strength of cable (GPa)
1	86.1	2.24	2.02
2	89	2.01	1.81
3	83.3	1.99	1.79
4	61	1.36	1.22
5	81	1.6	1.44
6	75	2.06	1.85
7	83.3	1.9	1.71
8	69.4	0.93	0.84
9	83.3	2.31	2.08
10	88.9	2.23	2.01

Figure 9: Concrete block surfaces after shearing

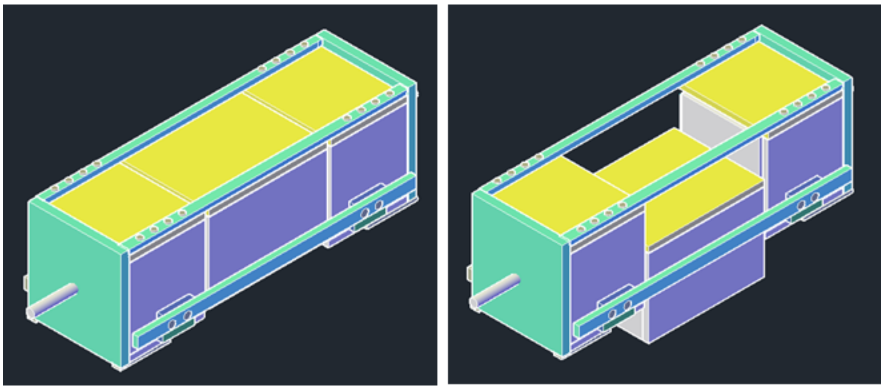

Figure 10: Schematic design of double shearing apparatus with no contacts between concrete blocks

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