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SINGLE SHEAR TESTING OF VARIOUS CABLE BOLTS USED IN AUSTRALIAN MINES

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ABSTRACT: Sixteen single shear tests were carried out on eight geometric cable variations provided for testing from Australian suppliers – Jennmar, Megabolt and Minova. Each test was subjected to varying pre-tension values of zero and 15 tonnes, exploring the effect of plain, spiral, bulbed, indented and a combination of plain and indented wire strands. The results obtained demonstrated that the shear strength of plain strand cable was higher than the spiral and/or indented profiled cables with direct correlation to the strands ultimate tensile strength. All the plain profiled cables experienced an element of partial debonding suggesting that their application at embedment length less than 1.8 m each anchor side may not be adequate. The spiral and indented profile strands provided greater bond strength at the cable-grout interface due to the surface roughness of the wires imposing an interlocking effect, leading to reduced shear displacement. The data suggests that the spiral profile was superior to the indented profile due possibly to the compromised integrity of the strand from the impact of stress raisers when creating the indented profile. No study was carried on the button indented profile cable bolts. This report is the first validation that type of apparatus selected to test the shearing capacity of a cable strand will not affect results.

INTRODUCTION

The practice of utilising cable bolts as a means of secondary support when the bolted height does not provide sufficient support has become an industry standard. Since the introduction of this ancillary support method, studies regarding the loading mechanisms of cable bolts have increased, particularly in the form of axial loading. Direct shear loading is still in its infancy with the majority of the research undertaken at the University of Wollongong (UOW). This paper continues and extends the work of the UOW Rock Bolting and Strata Control Research team by extending the scope of the studies to include single shear testing.

The new shearing apparatus was designed and constructed by Megabolt, a strata control product manufacturer, in response to the deficiencies of the current industry standard for the single shear testing of cable bolts outlined in BS7861-2:2009. The new methodology as designed allows for active reinforcement of the system and full encapsulation in a brittle host material allowing for the rock-grout interface to be assessed, creating more realistic results. The drawback of this methodology is the intense sample preparation required compared to preceding studies, which will impact for further studies to replicate the conditions of the test.

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Ground reinforcement can be classified in two distinct ways. Reinforcement is deemed primary if it is installed during the excavation sequence, whereas a support is secondary if it is installed sometime after the formation of the roadway. Conversely, ground support can be classified in terms of the active or passive support it imposes on the dynamic system. Active support applies a force to the rock mass modifying the mechanical behaviour to minimise displacement, particularly in jointed and loose rock units. Whereas, a passive ground support mechanism does not impose any initial force, rather it provides a resistive force as the rock deforms over time. Generally, rock bolts will be installed immediately post the creation of the excavation, followed, when necessary by the complementary ground support mechanism of cable bolts. The secondary support is utilised when the bolted height does not provide sufficient support, connecting the fractured zone to a more competent strata layer. Cable bolts consist of high strength steel wires coiled into a strand, which is installed into drilled holes and bonded to the rock mass by grout. The application of cable bolts, in conjunction with primary ground supports and a confining medium such as rock bolts and mesh, is presently a common industry standard for an integral excavation. The main function of cable bolts is to stabilise and strengthen rock mass, as well as provide resistance to bed separation and regulate post-failure deformation (Galvin 2016). Understanding the performance of cable bolts is becoming increasingly important to reduce expenditure without reducing its effectiveness in redistributing stress.

The two primary forces that underground support systems are subject to are axial loading and shear loading. Over the past 40 years, research has commenced into stimulating these loads to select the most appropriate cable for specific overlying and surrounding rock masses (Thomas 2012). Globally, the majority of the published research studies surrounding the performance of cable bolts is centered around axial loading of the cable bolt known as 'pull testing'. Data from pull testing is widespread as it can be conducted in the laboratory and the field due to its relatively simple testing method. Methods surrounding applying a direct shear load are still in its infancy due to its complexity and specialist laboratory process (Hutchinson and Diederichs 1996). Research reported in this paper is initiated with ACARP funding (project C24012), which focuses on cables bolts used in Australian mines and conditions.

PROCEDURE

Equipment

The single shear apparatus is a horizontally aligned integrated system, consisting of the shearing rig and a 120 t compression machine, as shown in Figure 1. The shearing cylinder is fabricated in two sections, each containing 1.8 m of concrete anchor cylinder, providing a centrally located shearing plane. The shearing cylinder is enclosed in steel clamps to provide confinement during shearing. The shear load is applied by four hydraulic rams, located at the bottom of the shear rig, with the applied shear load measured by a pressure transducer and analogue gauge.



Figure 1: Single shear test apparatus

The hydraulic pressure originates from either a hand pump or power pack of suitable capacity. The hydraulic pressure is fed to a manifold which distributes the pressure to the compression testing machine legs. A pressure transducer in conjunction with an analogue pressure gauge monitors the pressure in the manifold. The rate of loading is applied through manual application, with an aim to apply a constant load in line with F 432-04 (ASTM 2005) and BS7861-part 2 of between < 4 mm/mm/min. Linear Variable Displacement Transducers (LVDTs) were utilised to measure shear displacement at the shearing plane and any debonding at the cable ends. A datataker is used to record the readings of the pressure transducer and the LVDTs at a constant time intervals, which are utilised for further data analysis.

Sample preparation

Each cable bolt was installed in 250 mm diameter 3.6 m long and concrete cylinders. Cardboard cylinders were used as mould to make the test samples. Each cylinder consisted of a length and diameter of 900 mm and 250 mm accordingly. The axially laid central borehole within the sample was created through a 1000 mm steel rod with 8 mm diameter plastic conduit wrapped around the circumference of the rod to simulate rifling. The 40 MPa concrete with 10mm aggregate was prepared by an external body, to ensure that the concrete met requirements, slump tests were conducted on the fresh concrete to ensure integrity in relation to moisture and consistency of the mix. Once the concrete set the steel rod and plastic conduit were removed from each cylinder and then the cardboard mould was cut off. The concrete cured for a minimum of 28 days to allow for the nominal strength to be achieved. Each single shear test required four concrete cylinders with two sets of concrete cylinders fixed together to create the 1800 mm anchor cylinders on either side of the shear interface.

The frictionless shear interface was created through the use of two Teflon plates which had a thickness of 2 mm allowing for 4 mm opening between the concrete anchor cylinders to remove the frictional effects of the concrete contact at the interface as shown in Figure 2. Neoprene seals were also utilised to ensure the grout would not percolate from the annulus. The adhesion of the Neoprene seals and teflon plates to both of the cylinders occurred simultaneously with the second concrete anchor cylinder positioned in the frame after two minutes of curing time. Once the grout adaptor plate was glued to the other extremity of the 3600 mm span, the primary clamp was enclosed and fastened with bolts.



Figure 2: Teflon sheets with Neoprene seal for frictionless shear of the cable

Before grouting occurred, the pre-tensioning and grouting frame was positioned at an angle of 65° to allow for the bottom-up grouting method. This grouting method is where grout is propelled from the lower extremity of the cable filling the entire annulus area. Moreover, the angle allows for gravity to provide a weight force to prevent any air bubbles forming. Figure 3 shows the assembled cable bolt being grouted in the concrete cylinders and left to cure over a minimum period of one month. Stratabinder HS grout was used to encapsulate the cables in the concrete cylinders of all the cables used in the study. Once grouted the samples were left to cure for a minimum of 28 days prior testing.

Methodology

Once the mandatory time for curing was reached, each sample was disassembled from the frame and mounted to the shearing rig. When the sample was correctly positioned and fastened in the shearing rig, steel clamps, placed around the concrete blocks to provide a confining pressure to the sample. The action of applying a confining medium provided a more accurate replication of *in situ* conditions of the force applied to the cable from adjacent strata.



Figure 3: Angled cable grouted samples in 3.6 m concrete cylinder

Linear Variable Differential Transducers (LVDTs) were used to monitor displacement during cable shearing process as well as debonding. As shown in Figure 4, two LVDTs were mounted on both ends of the concrete cylinder to provide a numerical value for the cable axial displacement, when sizeable displacements affect the functioning of the strain gauges. Also, the extremity LVDTs provide information about the possible debonding of the cable. The pressure transducer, LVDT at the shear interface and the strain gauges were all connected to the data logger to monitor and record the data at a specified time interval. The use of strain gauges were soon abandoned in favour of LVDTs. A hydraulic power pack was connected to the hydraulic rams for vertical shearing. The pressure was applied manually to allow a loading rate of $< 4 \text{ mm/min}$.



Figure 4: An LVDT monitoring displacement at cable end with and without strain gauges

RESULTS AND DISCUSSION

Table 1 provides a summary of the data obtained from all of the sixteen single shear tests. The table presents the peak shear load of each cable with the corresponding shear displacement. Figure 5 shows photos of few sheared cables strands and Figure 6 shows profiles of different cable shear load-shear displacement of 15 test results. All the plain MW10 samples as well as SUMO cables experienced some element of debonding, differentiating it from other rough surface wires of spiral and indented cable samples. It is clear that the plain wire configuration reduces the bond strength at the cable-grout interface due to lack of surface roughness of the wires. Strain gauges were used to monitor axial displacement in the first six cables. The strain gauge and LVDT readings for the MW10 samples are shown in Figure 4, depicting debonding at certain displacements. Debonding occurred also in plain superstrand cable bolt (test 15). It is suggested that by using silastic to glue strain wires on the cable surface may have contributed to debonding of MW10 cables, however, both SUMO cables and superstrand cables were debonded with neither cables being coated with silicon glue on the plain wire surface. According to McKenzie (2014) some elements of partial debonding was observed in their past tests. This aspect of the study is being considered for further study.

Table 1: Cable bolt properties and test results

Test	Cable bolt properties				Pretension load (t)	Peak Shear load (t)	Displacement at peak (mm)	Cable debonding	Peak Shear Load / UTS (%)
	Product Name	Cable cross-section	Strand UTS (t)	Cable geometry					
1	MW10	Plain	70	No bulbs	15	68.3	93.3	Yes	97.6
2	MW10	Plain	70	6 bulbs	0	63.8	62.6	Yes	91.1
3	MW10	Plain	70	6 bulbs	15	60.4	56.0	Yes	86.3
4	MW9	Spiral	62	6 bulbs	0	47.7	43.5	No	76.9
5	MW9	Spiral	62	6 bulbs	15	43.1	47.4	No	69.9
6	MW9	Spiral	62	No bulbs	15	49.7	41.7	No	67.3
7	Secura HGC	Combination	68	6 bulbs	0	64.7	51.8	No	95.2
8	Secura HGC	Combination	68	6 bulbs	15	55.9	45.9	No	82.2
9	SUMO	Plain	65	6 bulbs	0	54.7	71.8	Yes	86.8
10	SUMO	Plain	65	6 bulbs	15	67.1	78.2	Yes	106.5
11	ID-SUMO	Indented	63	6 bulbs	0	46.4	46.9	No	73.7
12	ID-SUMO	Indented	63	6 bulbs	15	37.4	30.9	No	59.4
13	ID-TG	Indented	60	No bulbs	0	44.0	51.3	No	69.8
14	ID-TG	Indented	60	No bulbs	15	36.3	30.9	No	57.6
15	Superstrand	Plain	60	No bulbs	15	51.4	90.2	Yes	85.7
16	Garford	Plain	2 x 27	Bulbed	0	43.7	46.8	Yes	80.9

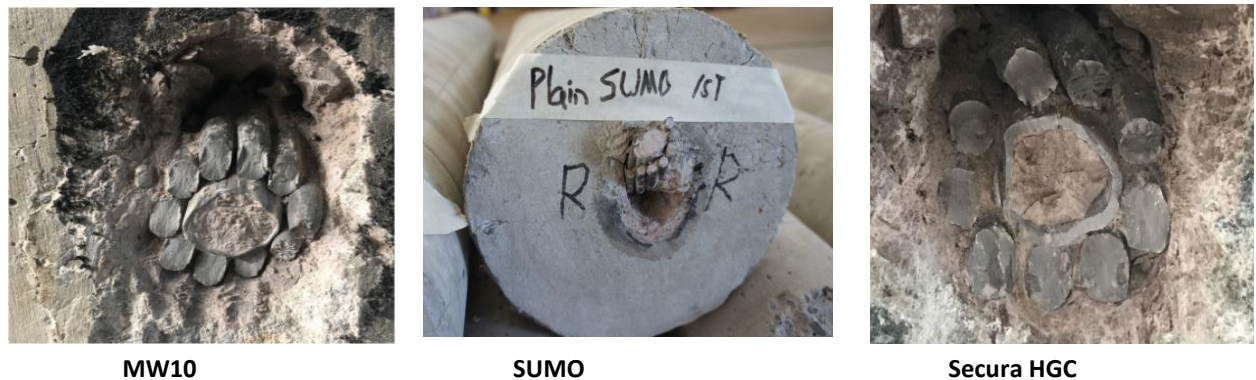


Figure 5: Three shear tests for three different cables

Tests 7 and 8 evaluated the shear loading of the Secura Hollow Groutable Cable (HGC) with and without the application of pre-tension. The Secura HGC consisted of four indented wires and five plain wires, surrounding the hollow central tube. The UTS of the Secura is 68 t, which is the second highest UTS strength of all the tested samples. Test 7 with zero pre-tension applied to the cable returned a peak shear load of 64.7 t and a shear displacement of 51.8 mm. Test 8 with 15 t pre-tension loads applied to the Secura HGC cable failed at shear load of 55.9 t and a displacement of 45.9 mm. Both the Secura bolt tests showed that the peak shear load decreased with increased pre-tension load. It is important to note that the Secura HGC did not undergo any displacement sourced from debonding as the profiled induced greater bond strength at the cable-grout interface due to surface irregularity. The study suggests that the combination of the two profiles, plain and indentation, appears to influence the cable anchorage performance.

The effect of increased pre-tension across nearly all the cables results in significant drops in shear load, except for the SUMO. Test 9 applied no pre-tension to the sample which recorded a peak shear load of 54.7 t with a shear displacement at peak load of 71.8 mm. Test 10 applied a 15 t pre-tension load resulting in the peak shear load of 67.1 t and a displacement at this load of 78.2 mm. The shear load of 67.1 t was above the expected Ultimate Tensile strength (UTS) of the plain sumo cable and the reason is unclear. In general, the pre-tensioned samples achieved a lower peak shear load, which does reflect on the hypothesis of stiffness reducing shear loads resisted.

It is worth mentioning that the general understanding of the shear strength of the steel being around 70 % of the ultimate tensile strength may not be applicable to cable strands when subjected to shearing. The cable strand invariably consists of several wires as well as a grout tube filled with grout, which behave differently when sheared.

The effect of spiral versus smooth wire on shear load was indicated by comparing the MW9 and MW10, even though the MW10 has an additional wire in the cable bolt. The spiral wire MW9 achieved average shear loads of 75% x UTS, whereas the smooth wire MW10 achieved average shear loads of 92% x UTS. Naturally the effect of MW10 debonding has an influence on results, with excessive shear displacement.

The effect of indented versus smooth wire on shear load was indicated by comparing the SUMO and ID-SUMO. The indented wire ID-SUMO achieved average shear loads of 66% x UTS, whereas the smooth wire SUMO achieved an average of 96.7% x UTS.

The effect on shear strength from the presence of bulbs in the Megabolt cable bolts was assessed by comparing tests 1 and 3 on the MW10, and tests 5 and 6 on the MW9. An increase in shear load of 13 – 15% was found in the Megabolt cables by removing bulbs. When assessing the effect of bulbs in the indented ID-SUMO and ID-TG, it was found that removing the bulbs decreased shear strength by 3 – 5%. Note that both TG and SUMO cables are made from the same hollow strand, and that the ID-

SUMO indented hollow cable used in the study was only a trial batch that were made for test work and is not marketed in Australia.

The plain Superstrand cable bolt with 15 t pre-tension load achieved 52.40 t peak shear load at 90 mm shear displacement. The result from test 16 indicated that the twin wire, Garford, cable bolt with 0 t pore-tension load reached 44.55 t at 46.8 mm of shear displacement.

There was no difference in the failure loads between the plain and spiral wires of Megabolt cables MW9 and MW10. Two 500 mm long wires of plain and spiral weighed 150.232 gm for spiral and 150.302 gm for plain wires. The failure loads were 6.6 t for MW 9 spiral wire and 6.8 for MW10 plain wire, demonstrating no loss in weight and strength in two wire versions. This is in confirmation with in-house results of failure load and elongation graphs observed from Megabolt internal test results, and are also evident from cross sectional photos of cut strands of MW9 and MW10 respectively as shown in McKenzie (2014). Secura HGC bolt indented wire lost around 10% of its strength and diameter as compared with plain wires. Similar weight and strength losses were observed in superstrand cable. Figure 7 shows the loss of strength in both Secura and Superstrand cables.

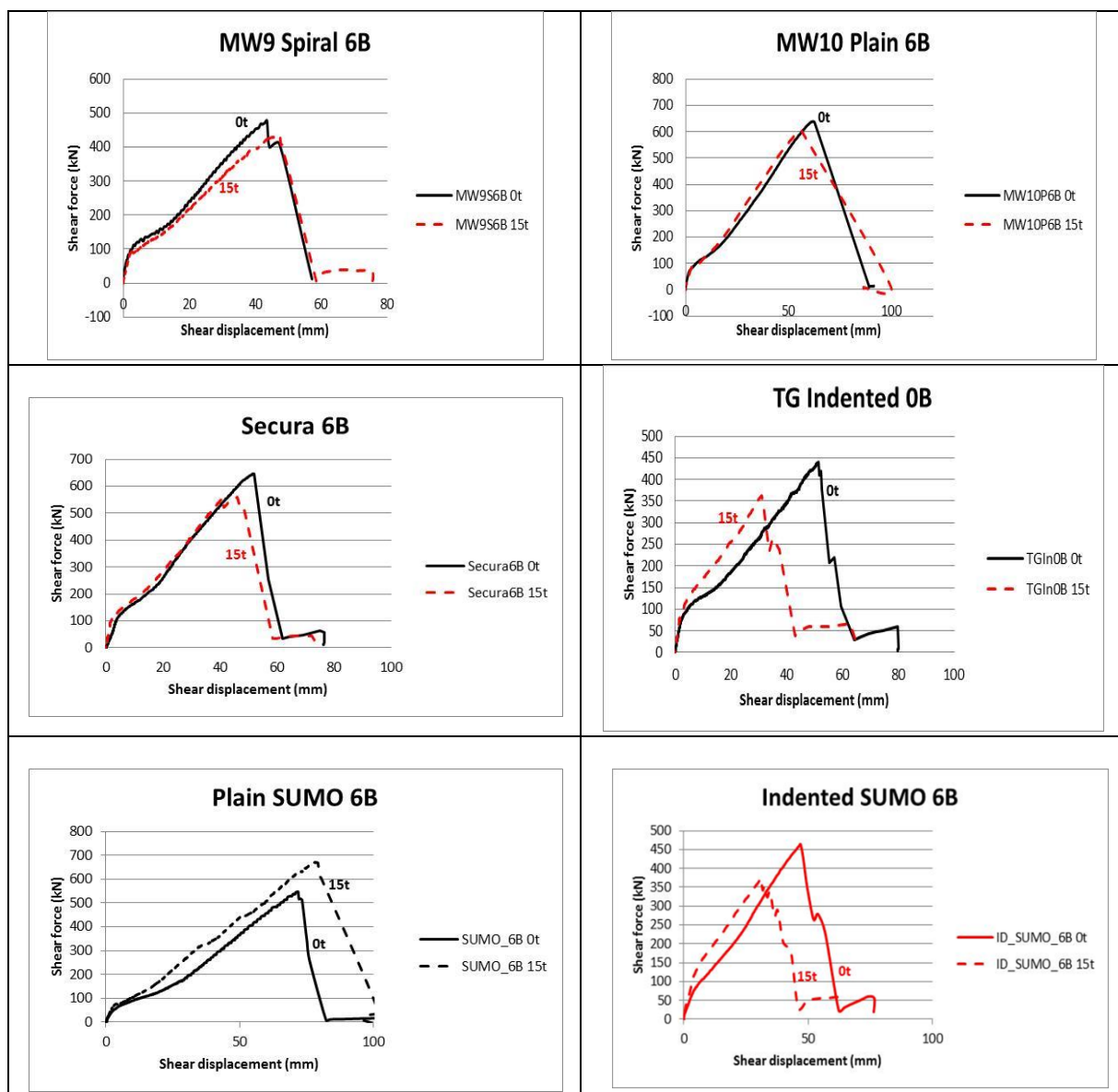
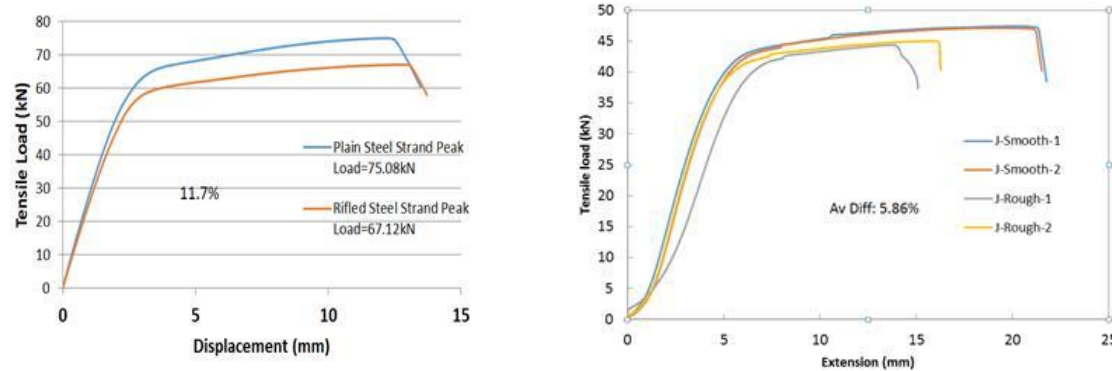


Figure 6: Shear force values Vs shear Displacement values for different tested cables



**Figure 7: Tensile loads of both Secura HGC and Superstrand cable wires
(Aziz, et al, 2010 and 2014)**

CONCLUSION

The new shearing apparatus addresses the deficiencies of the current British Standard (BS7861-2:2009) for the single shear testing of cable bolts. Twelve tests on different cable bolts confirmed that;

- The inverse relationship between increasing pre-tension load and the decrease in peak shear load and displacement.
- Cable bolts with rough wires result in a reduced shear load in comparison with cable bolts all smooth profiled wires.
- The effect of bulbing in some cables is inconclusive with both reduction and increases found in the comparison testing, however, bulbing may have influence on the integrity of the cable grout bonding.
- A cable bolt comprising a combination of smooth and spiral wires performed well in shear without debonding.
- Plain cables more readily debond at the cable-grout interface due to the smooth wire surfaces,
- The failure load difference between plain and profiled strands is proportional to the weight loss due to wire indentation. MW9 and MW10 strand wires were equal in weight

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