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Shear Testing of 28 mm Hollow Strand “TG” Cable Bolt

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ABSTRACT

Double shearing tests were carried out on the 28 mm (1 in) hollow strand Jennmar TG cable bolt to gain a better understanding of the shearing behavior of the cable. The first test was limited to a 50 mm (2 in) travel on the testing machine and produced a shear load of 900 kN (92 t) at the maximum 50 mm (2 in) displacement. The axial load generated on the cable bolt was 238 kN (24.3 t). In the second test, the machine travel was increased to 75 mm (3 in), and first strand failure of the cable, due to shear loading, occurred at 1,354 kN (138 t) vertical load at a vertical displacement of 59 mm (2.3 in). The cable axial load was in the order of 385 kN (39.3 t). Analysis of the failure mode and loads achieved showed that the cable strands bent and the concrete crushed along the shear plane; the shear loading across the concrete and grouted cable then reached the tensile strength of the steel wires.

INTRODUCTION

Cable bolts were introduced to the mining industry around 1970, initially to surface mining and underground metalliferous mining and then to coal mining in the early 1980s, mainly for roadway reinforcement as a secondary means of support. Cable bolts have since been used as both primary and secondary supports. As primary support, Fuller et al. (1994) described the application of cable bolts, known as FLEXIBOLT, for strata reinforcement in both Angus Place and Ellalong Collieries, in New South Wales (NSW), Australia. As secondary support, cable bolts have also been used as cable trusses, which act to support the immediate roof in a sling-like manner (Fabjanczyk and Tarrant, 1988; Fuller, et al., 1991; O’Grady and Fuller, 1992), and for reinforcement at higher stratification and beyond the rebar bolt length, mainly for anchoring lower strata layers immediately above the coal seam to the higher, competent bedding formation above. Initially cable bolt anchorage was by cementatious grouting and, since the 1990s, by chemical resin. The dominant type of cable bolts used for secondary support in Australian underground coal mines are 588 kN (60 t) capacity cables which are point anchored, pre-tensioned and post-grouted. Point anchored refers to a cable resin anchor. The cables are tensioned on the resin anchor; then the same cable is grouted by cementatious grout pumped to fill the annular gap around the cable from the collar of the hole to the resin anchor. Bulbs are located within the resin anchor section for mixing of the resin chemical components and efficient anchorage. The installation of these typically 8 m long cable bolts involves a lot of manual handling of the cables, lifting of heavy hydraulic tensioners, and exposure to resin grouts. Table 1 shows the specification of various cable bolts currently marketed and installed in Australian underground coal mines.

Because roof deformation loads cable bolts both axially and in shear, it is necessary to test cables for both tensile and shear strength. Axial loading is tested by pull testing in the laboratory (Goris et al., 1996) and in the field, while shear testing is only possible in the laboratory. Axial pull testing of the Jennmar TG cable produced a tensile strength of 618 kN (63 t), and this test was completed as part of the product development needs.

While attention to the strength of the cable bolt is generally focused on tensile strength, very little attention is paid to the cable strength in shear. Ironically failure in shear is one of the most damaging modes of failure, particularly in longwall gateroads and when lateral deformation of the immediate strata is more severe. Accordingly, and in an effort to study the effect of shear forces on cable bolt supports, this study deals with double shear testing of the cable bolt.

The TG bolt was developed in 2007 as a 618 kN (63 t) post-groutable bolt. The hollow strand cable bolt is a 28-mm (1-in) diameter, nine-wire-strand cable. Each element is 7 mm (0.3 in) in diameter and surrounds a 14 mm (0.6 in) hollow steel core tube. Figure 1 shows a cross sectional and side view of the cable. The TG cable is considered to have the following advantages over other similar cable bolt products as marketed in Australia:

- It has a central grout tube to achieve small grout annulus and therefore higher bond strength.
- It is flexible but has a reinforced central tube, which allows a barrel and wedge to be used on the strand. A barrel and wedge is the end fitting that locks onto the cable and sits below the plate on the outside of the drill hole.
- The steel strand chemical composition is resistant to stress corrosion cracking.
- It has a center grout tube resistant to corrosion.
- It has a simple bayonet grout fitting for push and ¼ turn attachment.

Table 1. Post-grouted cable bolts used in Australian coal mines.

Cable Type		UTS Strand (t)	Drill hole dia, mm (in)	Strand dia., mm (in)	Bulb dia., mm (in)	Bulbing in grouted section
TG Bolt		60	38-42 (1.5-1.7)	28 (1.1)	35 (1.4)	No
Bowen cable		60	42 (1.7)	21.8 (0.9)	38/33 (1.5/1.3)	Yes
Bulbed superstrand	B338	60	42 (1.7)	21.8 (0.9)	38 (1.5)	No
	B348		52-55 (2.0-2.2)	21.8 (0.9)	48 (1.9)	No
Megabolt/ Megastrand	MB9D	60	42-45 (1.7-1.8)	31 (1.2)	35 (1.4)	Yes
	MB8D	54	42-45 (1.7-1.8)	27 (1.1)	35 (1.4)	Yes
	MB9B	60	42-45 (1.7-1.8)	31 (1.2)	35 (1.4)	No
Post Groutable Hi-Ten		60	45-48 (1.7-1.9)	21.8 (0.9)	n/a	No
Mambo		60	42-45 (1.7-1.8)	21.8 (0.9)	34 (1.3)	Yes
15.2 mm (0.6 in) twin-strand		54	52-55 (2.0-2.2)	15.2 (0.6)	26 (1.0)	Yes

Figure 1. Cross section and side view of nine-strand TG cable bolt.

DOUBLE SHEAR TESTING OF TG BOLT

Shear testing of the 28-mm (1.1-in) diameter hollow strand "TG" cable was performed for the unbulbed grouted section at Wollongong University. The tests were carried out in a newly constructed, large double shearing apparatus containing a 50 MPa (7,251 psi) concrete mold. Each cable was installed in a newly cast concrete mold using "hi-thix" cable bolt grout supplied by Jennmar Australia. A 500 t capacity servo-controlled compression testing machine was used for the test. The aim of the study was to determine the shearing performance of the cable bolt under different lateral loading conditions and to assess the failure characteristics of the cable bolts. Two cable bolts, each 2 m (6.6 ft) in length, were tested. One cable bolt was pre-tensioned to an initial load of 50 kN (4.9 t), and the other to 90 kN (8.8 t).

Concrete Block Casting

Concrete blocks were cast for each double shearing test. Once mixed the concrete was poured into the greased marine plywood mold, measuring 1,050 mm x 300 mm x 300 mm (41 in x 12 in x 12 in). The mold was divided into three compartments separated by two metal plates. A plastic conduit 24 mm (0.9 in) in diameter was set through the center of the mold lengthways to create a hole for cable installation. The cast concrete blocks were left for the first 24 hours to set and harden in the mold. The blocks were then removed from the molds and kept in a moist environment for a period of 30 days to cure. The central hole of the concrete block was then rifle shaped reamed to 42-mm (1.7-in) diameter, ready for the installation of the cable with cement grout. The UCS value of the concrete was 50 MPa (7,252 psi), determined from testing the representative 100-mm (4-in) diameter cylindrical concrete specimens cast at the time of concrete preparation and pouring.

Cable Installation

The installation and encapsulation of the cable in the concrete block was carried out using Conbextra CB "hi-thix" cable bolt grout. This grout was high strength thixotropic grout (PC-201095). The following procedure was used in the grouting of the cable in the concrete blocks:

i. Four 20-mm (0.8-in) vertical holes were drilled from the topside of each of the concrete block molds to reach the 42-mm (1.7-in) cable installation hole as shown in Figure 2. The central two grout holes (A) were located on the central 450 mm (18 in) long block and were used to pour the grout into the 42 mm (1.7 in) hole. The two side holes (B and C) on the side blocks were to act as bleeder holes during the grouting stage.

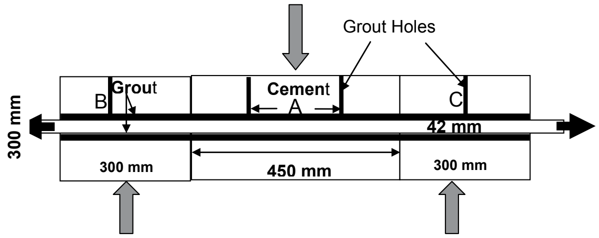

Figure 2. Double shear box.

ii. The cable was inserted in the 42 mm (1.7 in) hole and pretensioned to the desired load. Pretensioning was made possible by using special cable grips that were anchored at the ends of the cable bolt. Load cells with a capacity of 60 t were used to monitor the axial load developed during the initial cable bolt, the pre-tensioning and later, during the shearing stage. Prior to grouting, the annulus space between the cable and the 42 mm (1.7 in) holes at the either side of the concrete block were blocked with tight wrapping with sealant tape to stop the grout from seeping out.

iii. Grout was poured to fill the space between the axially drilled hole and the cable. The block was mechanically vibrated to remove any trapped air and reduce cavity formation.

iv. The concrete/grout/cable cast was left to cure for a minimum period of seven days prior to testing. The time of testing was dependent on the availability of the testing machine and other facilities.

Testing Program

Testing with Single Load Cell and Maximum 50 mm (2 in) Vertical Displacement

Testing was completed with single load cell and maximum 50 mm (2 in) vertical displacement. Figure 3 shows the general test setup with one 60 t capacity load cell, which was used to monitor the initial axial pre-tension load of 50 kN (49 t) on the cable bolt and subsequent load build up due to cable shearing. The vertical shearing of the central block was carried out at the rate of 1 mm (0.04 in) per minute.

Both the vertical load and vertical displacement were monitored together automatically and stored in data-loggers for further processing. Figure 4 shows the overall results of the first test, in which the total vertical displacement was limited to 50 mm (2 in). The graph contains the combined processed data of the applied shear load (blue graph) and the force developed along the axis of the hollow strand cable (green graph) during the shearing process.

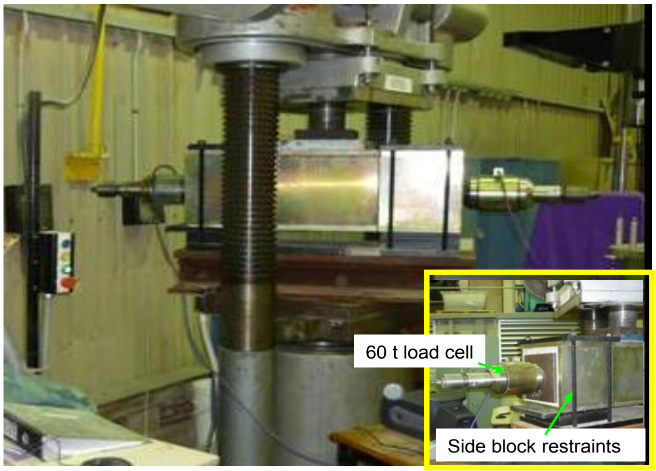

Figure 3. Assembled double shear apparatus in 500 tonne testing machine. Note the side block restraints.

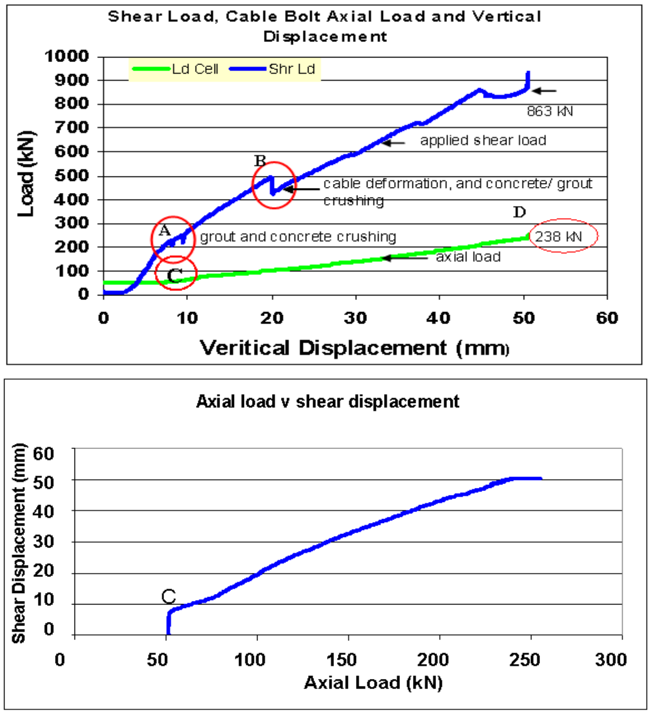

Figure 4. Double shear loading, vertical displacement and axial load generation on the cable bolt. The axial load was monitored using a single 60 t load cell.

The total vertical load applied was in the order of 900 kN (88 t). This load was only possible for the maximum allowable displacement of 50 mm (2 in) (Figure 4a). The maximum axial load developed on the cable was in the order of 238 kN (24.3 t) at D, corresponding to the total displacement of 50 mm (2 in). Figure 4b shows the profile of axial load build up on the cable as a result of vertical shear displacement. The extent of concrete crushing, moving inwards the centre of the middle block was around 60 mm (2.4 in) as shown in Figure 5. Point A on the shear load/ vertical displacement graph (Figure 6) is attributed to the possible initial deformation of the central cable's hollow core tube as well as grout and concrete crushing at the sheared zones. Point B indicates the effect of further and sudden deformation of the concrete, grouts, and cable strands.

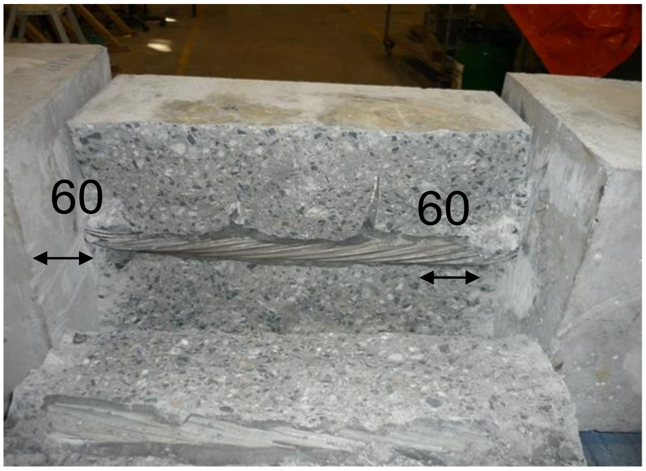

Figure 5. Concrete / grout crushing and cable bolt deformation in the vicinity.

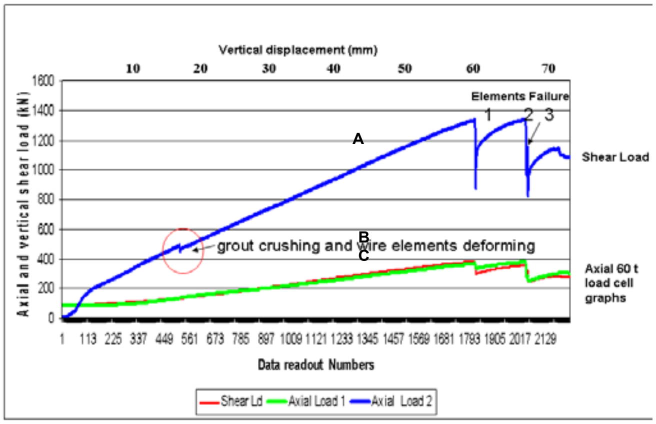

Figure 6. Double shear loading, vertical displacement and axial load generation on the cable bolt using two load cells with maximum vertical displacement of 75 mm.

Testing with Double Load Cell and Maximum 75 mm (3 in) Vertical Displacement

The second test was carried out with two load cells monitoring the axial load generated on the cable. One cell was mounted on each side of the cable as previously shown in Figure 3. Initially the bolt was subjected to an axial load of 100 kN (10.1 t) during encapsulation period of the cable in concrete blocks. The system was then left for three weeks to cure. During this period the initial pre-tension load was dropped to 90 kN (9.2 t). The total vertical shearing displacement was increased to a maximum of 75 mm (3 in), which was the maximum possible stroke travel of the compression-testing machine. The testing condition was maintained similar to the first test with regard to load application and displacement monitoring frequencies.

The strand elements of the hollow strand cable began to fail when the vertical shearing load exceeded 1,354 kN (138 t) as depicted in Figure 6 by the blue graph (graph A). This failure occurred when the bolt was sheared some 60 mm (2.4 in) vertically. Points 1, 2 and 3 are the points of the cable element strand failures. Strand elements 2 and 3 occurred at the same time and these two failures may have occurred simultaneously on either side of sheared central block. Table 2 shows strands failure load and vertical displacements.

The axial load developed on the cable bolt due to shearing was observed by two axial load cell readings B (green) and C (brown) respectively. The maximum axial load developed in the second test was in the order of 385 kN. This occurred at a vertical displacement of 60 mm (2.4 in).

The failure loads shown in the second column of Table 2 are the maximum failure loads recorded for the first cable bolt element (strand) failure during shearing of the cable at two shear planes (i.e., double shear). Thus, the failure loads per side are shown in column three of Table 2. It must be noted that the failure loads shown are those needed to overcome both the cable element strength as well as the shearing of the surrounding concrete shear planes, which are subjected to gradually increasing pre-tension load.

Next, one 400 mm (16 in) long cable strand and 485 length of the central hollow tube were tested for ultimate tensile failure. The failure load of the 7 mm (0.3 in) strand was 72 kN (7.3 t), and that of the hollow central tube was 4.8 kN (0.5 t). Figure 7 shows the load versus elongation of both the 7 mm (0.3 in) strand and hollow inner core of the TG cable bolt.

Given that the tensile strength of the cable is 618 kN (63 t), and considering that the hollow central steel is not a load-bearing element, then the entire load is carried by 7 mm (0.3 in) diameter strands. As seen in Figure 8, it is obvious that the cable strands' failures occurred due to a combination of bending and tension and not solely due to shear. All strand failures were of cone and cup failure with necking, which is a characteristic of the steel failure in tension as shown in Figure 9. This is expected, as the concrete was, in general, more deformable and softer than steel. This was also evident from the heavily crushed zone in the vicinity of the shear planes (Figure 5).

If the cables were sheared, then the shearing load of the cable would be around 2/3 or 70% of the tensile load, based on the past tests of the ordinary 24 mm (0.9 in) diameter steel bolts using the conventional guillotine shearing test, and on common knowledge of steel strength properties.

Applying this scenario to the cable strand, the failure load of the cable strand would be in the order of 44kN (4.4 t) instead of 72 kN (7.3 t) as determined from the laboratory tests. It must be mentioned that only the central core tube will be likely to fail in shear as it has a failure load of around 0.5 tonnes and was thus squashed and flattened at the time of vertical loading/shearing. Thus it can be concluded that the maximum load per strand can be between 44 (4.5 t) and 72 kN (7.3 t) depending on the nature of the failure.

Table 2. Cable elements shear failure loads and displacements.

Element	Failure load-double plane shear (kN)	Failure load per shearing side (kN)	Vertical displacement mm (in)
1	1,354	677	59 (2.3)
2	1,353	676.5	66 (2.6)
3	1,163	581.5	66.3 (2.61)

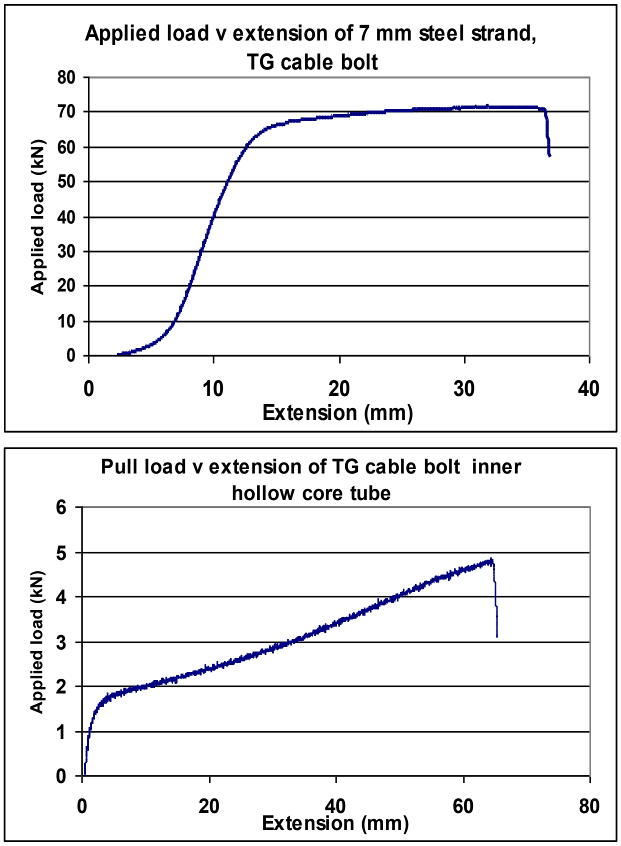

Figure 7. Load versus elongation of TG cable bolt strand (top) and inner hollow tube (bottom).

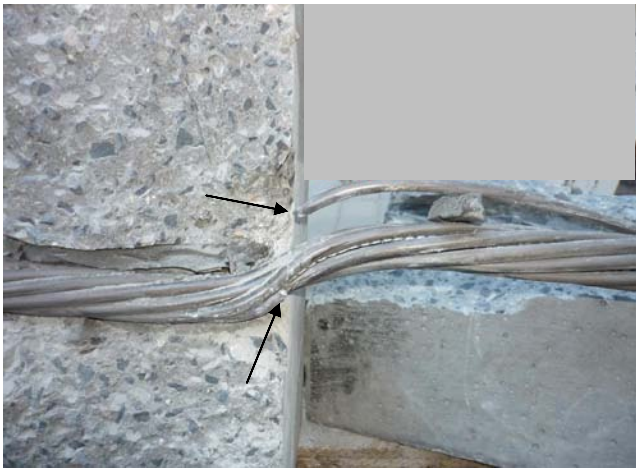

Figure 8. One element failure on the LHS sheared plane face.

Figure 9. Cone and Cup strand failures.

CONCLUSIONS

The first test was limited by a 50 mm (2 in) travel on the testing machine and produced a shear load of 900 kN, with axial load generated on the cable bolt reaching 238 kN (24.3 t).

In the second test the machine travel was increased to 75 mm (3 in); cable failure due to shear loading was achieved at a 1,354 kN (138 t) load and vertical displacement of 59 mm (2.3 in), with cable axial load in the order of 385 kN (39.4 t). Analysis of the failure mode and loads achieved indicate that the cable strands bent and the concrete crushed along the shear plane; the shear loading across the concrete and grouted cable then reached the tensile strength of the steel wires. The central hollow steel core tube is not a shear load-bearing element of the cable bolt.

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