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Peter Craig
Jennmar Australia

Naj Aziz
University of Wollongong, naj@uow.edu.au

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SHEAR TESTING OF 28 MM HOLLOW STRAND "TG" CABLE BOLT

Peter Craig¹ and Naj Aziz²

ABSTRACT: Cable bolts were introduced to the coal mining industry in the early 1980's mainly for roadway reinforcement as a secondary means of support. Their application is dictated by the nature of the stratification, ground stress conditions and the size of the opening. Double shearing tests were carried out on the 28 mm hollow strand Jennmar "TG" cable bolt, two tests were conducted to evaluate the shearing characteristics of the bolt and to gain a better understanding of the shearing behaviour of the cable. The first test was limited by a 50 mm travel on the testing machine and produced a shear load of 900 kN (92 t) at the maximum 50 mm displacement, 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, cable failure due to shear loading was achieved at 1 354 kN (138 t) load and a vertical displacement of 59 mm, with cable axial load in the order of 385 kN (39.3 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.

INTRODUCTION

Cable bolts were introduced to the mining industry around 1970, initially to surface mining and underground metalliferous mining and later on to coal mining in the early eighties mainly for roadway reinforcement as a secondary means of support of the last century. 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 NSW. 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 and competent bedding formation above. Initially cable bolt anchorage was by cementitious grouting and since 1990's 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. The installation of these typically 8 m long cable bolts involves a lot of manual handling of the cables, lifting of heavy hydraulic tensioners, along with exposure to cementitious 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 represents one of the most damaging aspects of the cables' credibility particularly in longwall gateroads and when lateral deformation of the immediate stratification is at its 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 diameter, nine wire strand cable. Each element is 7 mm in diameter, which surrounds a 14 mm 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:

¹ Jennmar Australia

² University of Wollongong

- It has a central grout tube to achieve small grout annulus and therefore higher bond strength
- Its flexible but reinforced central tube which allows a barrel and wedge to be used on the strand
- Its steel strand chemical composition resistant to stress corrosion cracking
- It has centre grout tube resistant to corrosion
- It has 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 Diameter (mm)	Strand Diameter (mm)	Bulb Diameter (mm)	Bulbing in Grouted Section	
TG Bolt	60	38 - 42	28	35	No	
Bowen Cable	60	42	21.8	38 / 33	Yes	
Bulbed SuperStrand	B338	60	42	38	No	
	B348		52 - 55	21.8	48	No
Megabolt / Megastrand	MB9D	60	42 - 45	31	35	Yes
	MB8D	54	42 - 45	27	35	Yes
	MB9B	60	42 - 45	31	35	No
Post Groutable Hi-Ten	60	45 - 48	21.8	n/a	No	
Mambo	60	42 - 45	21.8	34	Yes	
15.2mm Twin-strand	54	52 - 55	15.2	26	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 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 concrete mould. Each cable was installed in newly cast concrete mould 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 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 mould, measuring 1 050 mm x 300 mm x 300 mm. The mould was divided into three compartments separated by two metal plates. A plastic conduit 24 mm in diameter was set through the centre of the mould 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 mould. The blocks were then removed from the moulds 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 diameter, ready for the installation of the cable with cement grout. The UCS value of the concrete was 50 MPa, determined from testing of the representative 100 mm 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 vertical holes were drilled from the top side of each of the concrete block moulds to reach the 42 mm cable installation hole as shown in Figure 2. The central two grout holes (A) were located on the central 450 mm long block and were used to pour the grout into the 42 mm hole. The other two side holes (B and C) on the side blocks were to act as bleeder holes during the grouting stage.
- ii. The cable was inserted in the 42 mm hole and pretensioned to the desired load. Pretensioning was made possible by using special cable grips which were anchored at the ends of the cable bolt. These grips were supplied by Jenmar Australia. 60 t capacity load cells were used to monitor the axial load developed during the initial cable bolt pretensioning and later during the shearing stage. Prior to grouting the annulus space between the cable and the 42 mm 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 air trapped and hence reduce cavity formation.
- iv. The concrete/grout/ cable was left to cure for a minimum period of not less than seven days prior to testing. In any case the time of testing was dependent on the availability of the testing machine and other facilities.

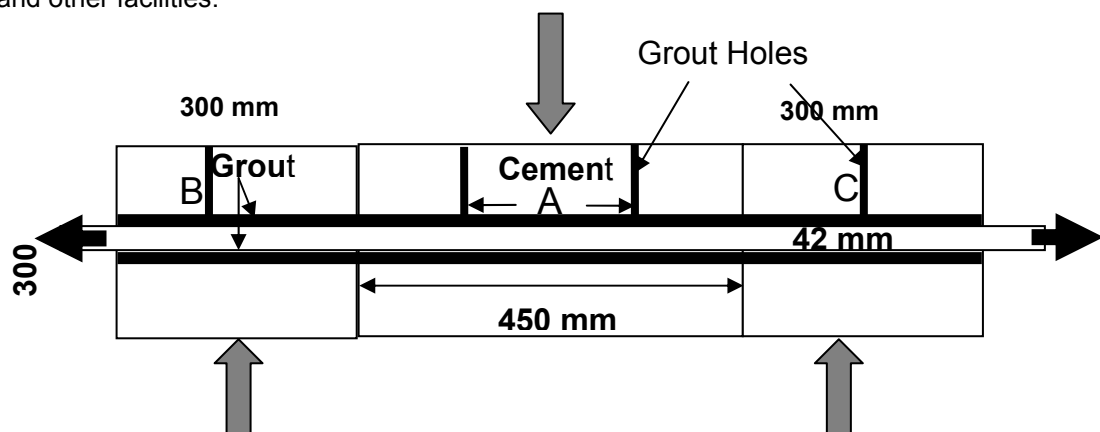


Figure 2 - Double shear box

Testing

Testing with single load cell and maximum 50 mm vertical displacement

Figure 3 shows the general test setup with one 60 t capacity load cell which was used to monitor the initial axial pretension 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 per minute.



Figure 3 - Assembled double shear apparatus in 500 tonne testing machine

Both the vertical load and vertical displacement were monitored automatically together 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. 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.

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 (Figures 4 and 5). Points A on the shear load /vertical displacement 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 as shown in Figure 6. Point B indicates the effect of further and sudden deformation of the concrete and grouts as well as cable strands. The extent of concrete crushing, moving inwards towards the centre of the middle block was around 60 mm as shown in Figure 6. The maximum axial load attained by the cable was in the order of 238 kN (24.3 t) at D, corresponding to the total displacement of 50 mm (Figures 4, and 5).

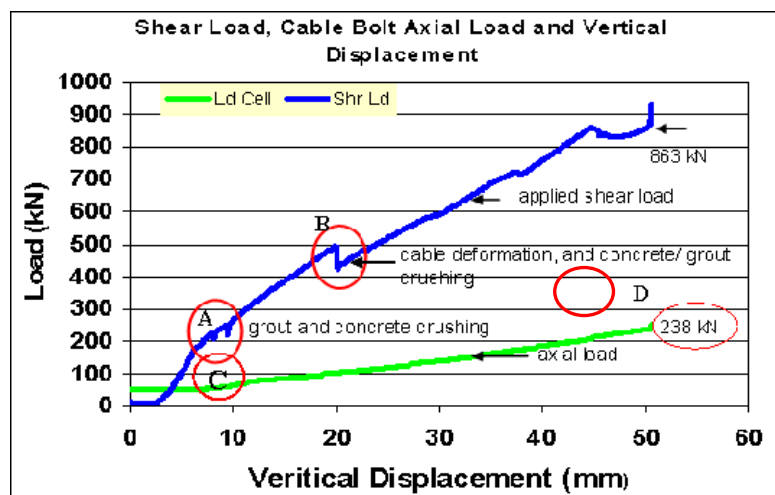


Figure 4 - Double shear loading, vertical displacement and axial load generation on the cable bolt. The axial load was monitored by a single 60 t load cell

Testing with double load cell and maximum 75 mm 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 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 pretension load was dropped to 90 kN (9.2 t). The total vertical shearing displacement was increased to a maximum of 75 mm, 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.

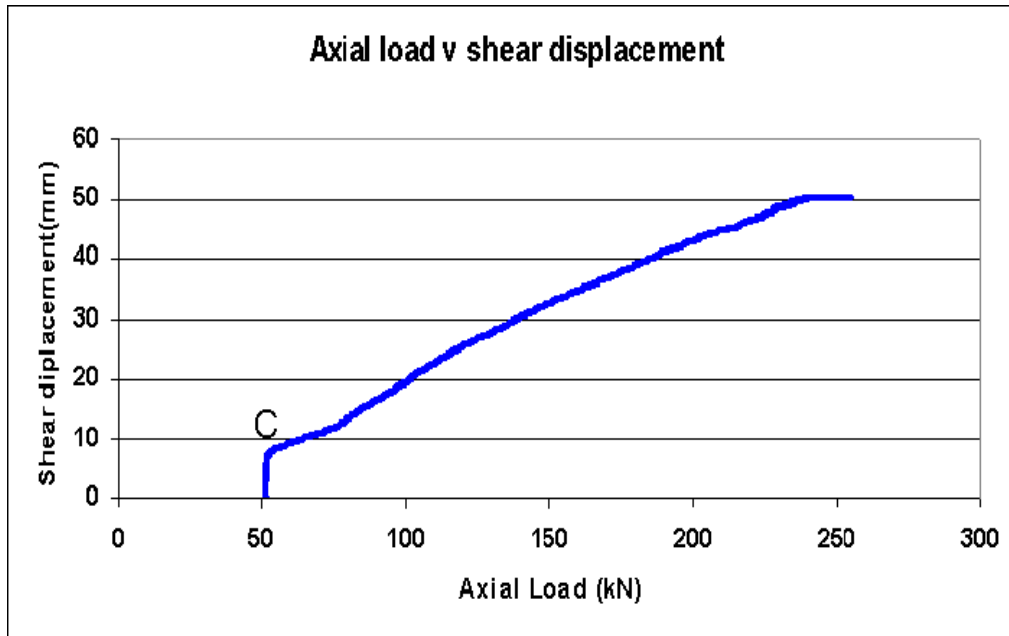


Figure 5 - Vertical shear displacement and axial load on cable bolt

As seen in Figure 7, the strand elements of the hollow strand cable began to fail when the vertical shearing load exceeded 1 354 kN (138 t) as depicted by Blue graph (graph A). This failure occurred when the bolt was sheared some 60 mm vertically. Points 1, 2, 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



Figure 6 - Concrete / grout crushing and cable bolt deformation in the vicinity

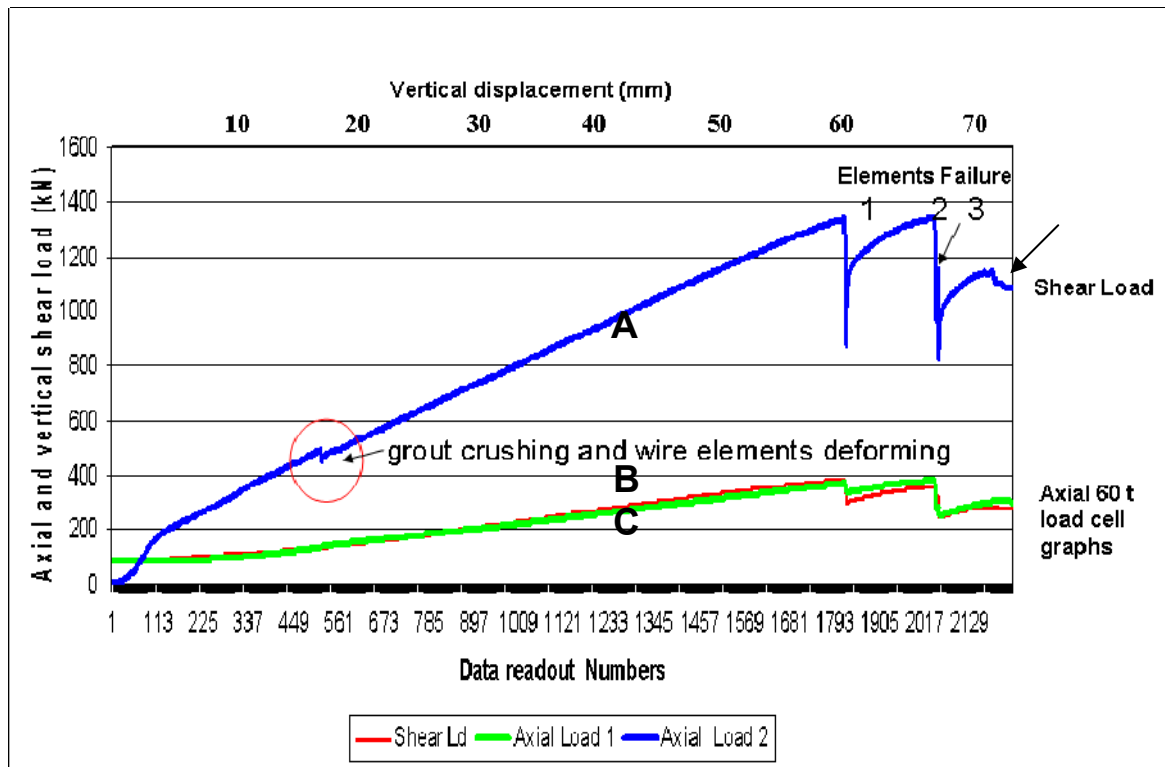


Figure 7 - Double shear loading, vertical displacement and axial load generation on the cable bolt using two load cells with maximum vertical displacement range of 75 mm

The failure loads shown in column two in 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 to overcome both the cable element strength as well as the shearing of the surrounding concrete shear planes, which are subjected to gradually increasing pretension load.

Table 2- Cable elements failure loads and displacement

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

Next, one 400 mm long cable strand and 485 length of the central hollow tube were tested for ultimate tensile failure. The failure load of the 7mm strand was 72 kN (7.3 t), and that of the hollow central tube was 50 kN (5.1 t).

Given that the tensile strength of the cable is 618 kN (63 t), and considering that the hollow central steel is of concertina shape and of ductile material, then the central core is unlikely to bear significant proportion of the applied shearing load as would the strands, which are designed to bear.

As seen from Figures 8-11, it is clearly obvious that the cable strands' failures occurred in tension and not in shear. All strand failures were of cone and cup failure and necking which are a characteristic of the steel failure in tension (Figures 8-9). 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 6).

If the cables were realistically 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 diameter steel bolts using the conventional guillotine shearing test, and is a common knowledge on steel strength properties.



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

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). It must be mentioned that only the central core tube will be likely to fail in shear as it was 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.



Figure 9 - Cone and Cup strand failure



Figure 10 - Strand necking and flattened tube

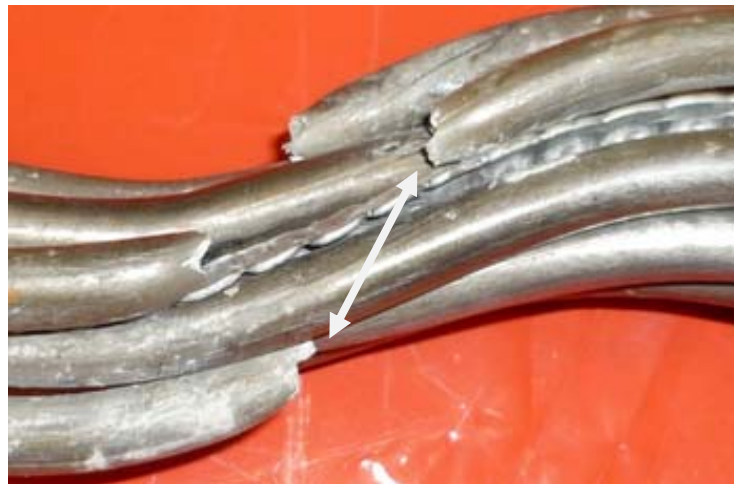


Figure 11 - Strand necking and flattened tube

CONCLUSIONS

The first test was limited by a 50 mm travel on the testing machine and produced a shear load of 900 kN at the maximum 50mm displacement, 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, cable failure due to shear loading was achieved at 1 354 kN (138 t) load and vertical displacement of 59 mm, 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.

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