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SHEAR STRENGTH PROPERTIES OF HILTI PLAIN AND INDENTED STRAND CABLE BOLTS

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ABSTRACT: An investigation into the performance of two 22 mm diameter, 60 tonne tensile strength capacity Hilti cable bolts in shear was conducted using the double shear testing apparatus at the laboratory of the School of Civil, Mining and Environmental Engineering Faculty of Engineering and information sciences, University of Wollongong. The tested cable bolts were (a) Hilti19 wire HTT-UXG plain strand and (b) Hilti 19 wire HTT-IXG spirally indented strand cable bolt, with indentation only on the surface of the outer strands. Both cable bolts were of sealed wire construction type, consisting of an outer 5.5 mm diameter strand layer overlying the middle 3 mm diameter wire strands. Both layers are wrapped around a single solid 7 mm diameter strand wire core. The double shearing test was carried out in 40 MPa concrete blocks, contained in concrete moulds. The cable bolts were encapsulated in concrete using Minova/ Orica FB400 pumpable grout. Prior to encapsulation, each cable bolt were pretensioned initially to 50 kN axial force. A 500 t capacity servo controlled compression testing machine was used for both tests, and during each test the vertical shear displacement was limited to 70 mm on travel. The rate of vertical shear displacement was maintained constant at 1 mm/min. The maximum shearing load achieved for the plain strand cable was 1024 KN, while the indented cable peak load was 904 kN, before the cable bolt strands began to individually snap, which lead to the cable bolt break up into two pieces. It was found that indentation of the cable bolt's outer strand weakened both the tensile and shearing strength.

INTRODUCTION

Cable bolt usage in Australian coal mines is on the increase, because it is mostly used as A secondary support to supplement the primary support system for strata reinforcement. Several factors have contributed to the increase in cable bolt usage in mines; the most prominent of these are a better understanding of the principals of rock mechanics and strata control, and better management of difficult ground conditions. As a consequence, the reliance on Short Encapsulation Pull Testing (SEPT) of cable bolt cannot be considered as adequate alone for providing realistic answers to the credibility of the installation in given ground condition. The unwinding/unscrewing of the cable bolts from their anchorage medium, and shear behaviour across the stratified formation represent important challenges to be addressed. A number of papers have been reported on studies examining the load transfer and unscrewing characteristics of cable bolts (Clifford, *et al.,* 2001; Tadolini, *et al.,* 2001 and 2012; Thomas, 2012), and there have been significant variations in the design to include both plain and indented cable bolts of different sizes and combinations. The increased variations in cable bolt configurations and designs have also generated deep interest in shear failure of tendons'. *In situ* studies in cable bolt shear are difficult to conduct, but can carried out in laboratory simulated conditions. Goris *et al.*, (1996), carried out shear testing of cable bolts using pairs of 0.025 m^3 concrete blocks made from fine sand-concrete mix having an average 28 days compressive strength of 69 MPa. The concrete mixture was poured into steel moulds that contained an aluminium-cast joint surface prints. The tested cable was installed across two concrete blocks with the desired shear surface roughness produced as off prints of aluminium joint surface moulds. The study reported that a cable bolt placed across a joint more than doubled shear resistance of shear blocks having both smooth and rough joints.

Testing of the cable bolt in shear using the double embedment assembly (Figure 1) as recommended by the British Standard (BS 7861-2:2009) is an un-realistic approach. Guillotining of the cable tendon, leading to true shearing of the metal elements is not what occurs when a cable bolt is sheared across a rock joint. In reality the past laboratory experiences have shown that the failure of the cable bolt in rock or composite material is a combination of both tensile and shear failure manifested with crushing of the rock or concrete surrounding the zone of the sheared plains, (Craig and Aziz, 2010a, b). These findings were also demonstrated by numerical simulations in both rock bolts (Jalalifar, *et al.*, 2006). Accordingly,

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the application of the double shear system for testing cable and rock bolts in concrete moulds is the subject of reporting in this paper.

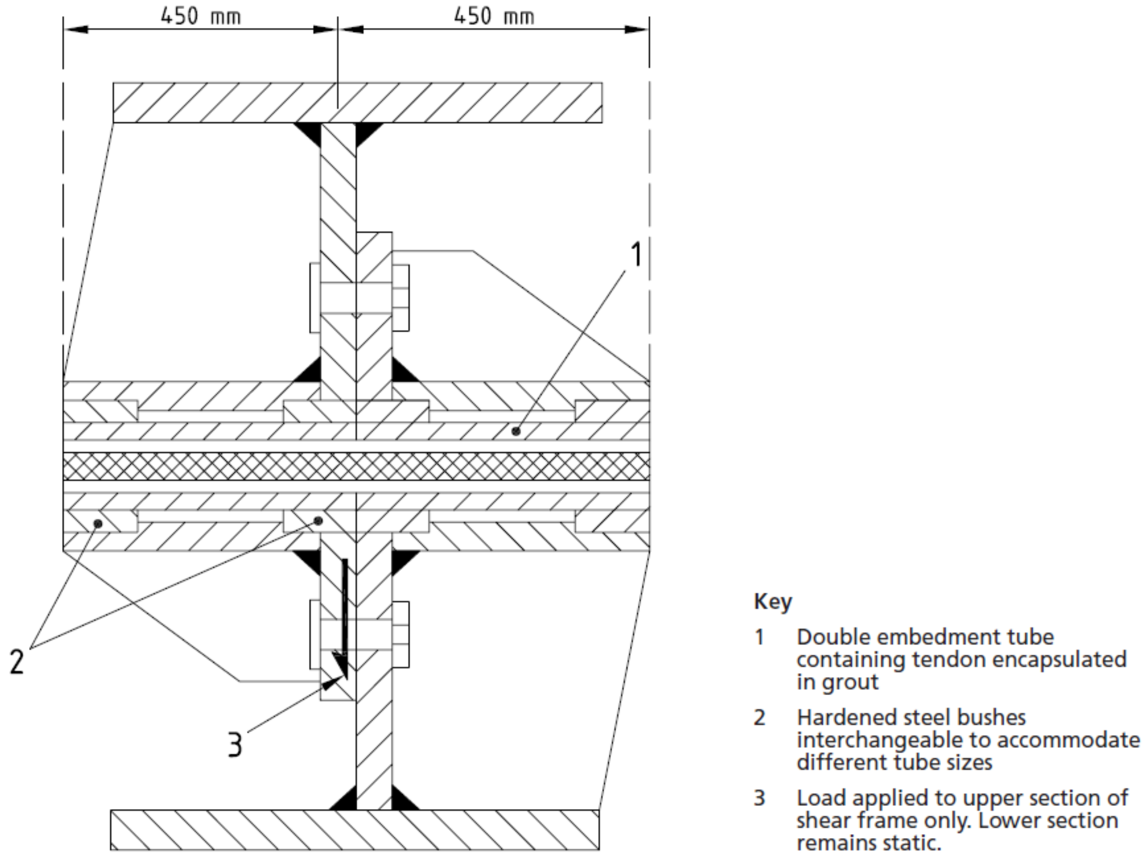

Figure 1 - Sectional diagram of double embedment shear frame (BS 7661-2: 2009)

CABLE BOLT DESCRIPTION

The tested cable bolts were (a) Hilti19 wire HTT-UXG plain strand and (b) Hilti 19 wire HTT-IXG spirally indented strand cable bolt, with indentation only on the surface of the outer strands. Both cable bolts were of sealed wire construction type, consisting of an outer 5.5 mm diameter strand layer overlying the middle 3 mm diameter wire strands. Both layers are wrapped around a single sold 7 mm diameter strand wire core. Both Hilti plain and indented cable-bolts shown in Figure 2 (A and B) consisted of 19 strands (9 x9x1) of seal construction wire rope as shown in Figures 2C. The cables were both 22 mm in diameter with the rope thread profiles being "Left Hand Lang's Lay" construction type. The lay length of the strands in both cables was 300 mm. Details of both cables specifications are shown in Table 1.

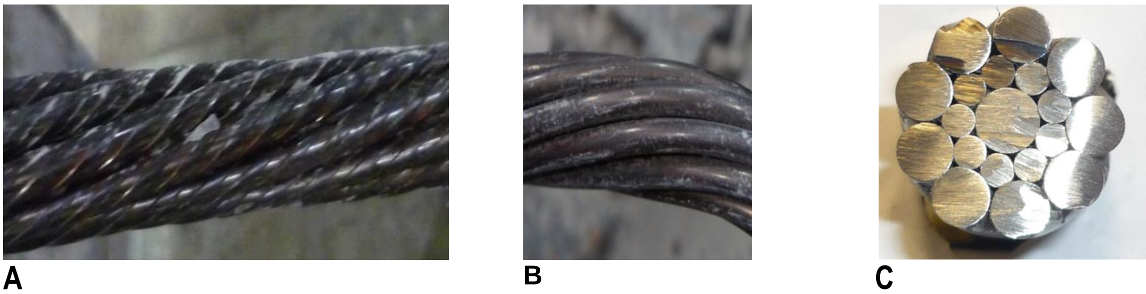

Figure 2 - Hilti 19 wire plain and indented strand cables

CONCRETE SAMPLES PREPARATION AND CABLE BOLT INSTALLATION

Concrete block casting

Figure 3 shows a general layout of an assembled double shear apparatus with installed cable bolt. Each double shear testing process required three cement /mortar concrete blocks with two outer 300 mm side cubes and a central rectangular block 450 mm long. The casting of the concrete blocks for the test was carried out in the steel frame of the double shear apparatus. Once mixed, the cement mortar was poured into each section of the 20 mm thick steel frame. A plastic conduit 20 mm in diameter was set through the centre of the mould lengthways to create a hole for cable installation in the concrete blocks. Once the concrete was set, the plastic conduit was removed from the center of the blocks. The center hole was subsequently reamed to a 27/28 mm diameter rifled shaped hole, using twin wing drill bits. The UCS value of the concrete used in this study was 40 MPa, determined from testing the representative 100 mm diameter cylindrical concrete samples.

Table 1 - specification of Hilti Cable bolts

Performance data	Hilti HTT-UXG (Plain strand)	Hilti HTT-IXG (Indented strand)
Ultimate yield load	495 kN (50 t)	425 kN (43 t)
Ultimate failure load	573 kN (58 t)	510 kN (52 t)
Bolt Diameter	21.8 mm	21.8 mm
Cross sectional Area	312.9 mm^2	277 mm^2
Mass	2.482 kg/m	2.2 kg/m
Outer strand diameter	5.5 mm	5.5 mm
Inner lay strand diameter	3.0mm	3.0 mm
Core strand diameter	7.0 mm	7.0 mm
Hole diameter / Collar Reaming size	28 mm/55 mm	28 mm/55 mm

Cable bolt installation in concrete blocks

The installation of the cable bolt in a three pieces concrete mould was carried out using Minova FB400 cable bolt grout. The cable bolt was inserted into the central hole of the assembled concrete blocks. A 60 t load cell was then mounted on one side of the protruding cable bolt using a barrel and wedge assembly. This was followed by the addition of the grout injection sleeve/and bolt tensioner assembled on the other side of the assembled double shear box, and was held in place using another barrel and wedge. The cable bolt was pre- tensioned to an axial load of 50 kN by a torque wrench prior to grouting.

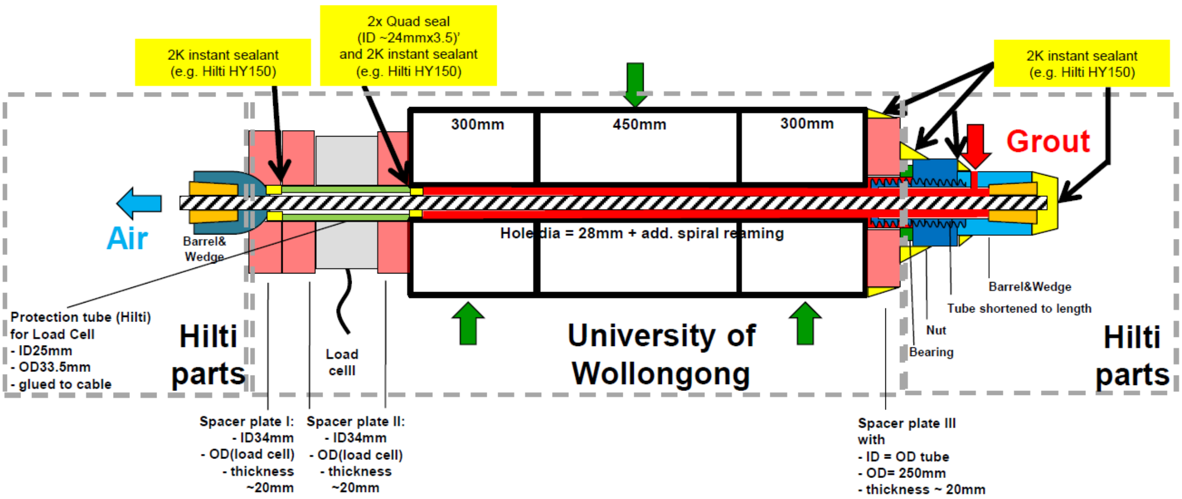

Figure 3 - A schematic layout of the cable installation assembled in concrete blocks

Grouting of the cable bolt in concrete was achieved by pumping Orica / Minova FB400 grout into the hole containing the cable bolt using grouting sleeve, and in accordance with the established process of grouting. Quad Seals were used to seal around the cable in the load cell side of the concrete block in order to protect the load cell from being contaminated by the grout. Special grout seals were used to minimise grout outflow during pressure injection of the grout. Air was allowed to escape from one end of the assembled cable bolt system and along the free cable strand end as grout was pushed through the hole length.

Testing procedure

The assembled double shear box apparatus was then placed on a carrier base frame consisting of a parallel pair of rail track sections welded to a 35 mm thick steel plate. The whole assembly was mounted between the 600 x 600 mm loading plates of the 500 t compression testing machine as shown in Figure 4. The outer 300 mm side concrete cubes were seated on 75 mm high steel blocks, leaving the central 450 mm long block free to move vertically down during the shearing process. The rate of shearing of the double shear apparatus the middle section was maintained constant at 1 mm/min for the 75 mm of vertical displacement. The rate of loading and displacement was monitored and simultaneously displayed visually on a PC monitor.

Figure 4 - Double shearing apparatus loaded in 500 t Avery compression testing machine

RESULTS AND ANALYSIS

Indented cable bolt

Figure 5 shows the applied shear load and axial load in the cable versus the vertical displacement of the central block of the double shear apparatus with indented cable bolt. The maximum vertical load was 904 kN, which occurred when the vertical travel of the central block reached approximately 52 mm. The maximum axial load developed at the cable bolt was 254 kN.

Various shear load that occurred beyond the vertical displacement of 52 mm were due to individual cable strand failures (strand snap). The relatively larger shear load drop, post the 904 kN maximum load, was likely due to the larger diameter (5.5 mm diameter) outer strand as well as the central core strand failures (7 mm diameter), while small drops are indicative of the small 3 mm diameter strand failure. It is interesting to note that the outer strand failures are also marked by drops in the axial load on the cable bolt, as monitored by the 60 t load cell. The number of visible sudden drops on the load displacement graph appears to be slightly less than the total number of the 19 failed strands. This is clearly evident from Figure 6a of the failed /snapped cable section as retrieved from dismantled blocks. Characteristically, the snapped cable strand ends depict strand failures as a combination of tensile and shear failures, which are what would occur in reality when the cable is sheared in a rock mass. This kind of failure is the result of bending of the cable in the vicinity of the sheared plains where the concrete has crushed for a length of up to around 60 mm from the sheared joint plains as demonstrated in Figure 6 b.

Note that the loading changes A and B shown in Figure 5 are attributed to wedge and barrel settlement / adjustment during the early start of cable bolt loading as the cable bolt begins to take extra axial load due to the central / lateral shear loading.

Plain strand cable

Figure 7 shows the load /displacement profiles of the second test carried out on 22 mm diameter Hilti 19 plain strand cable. The plain cable bolt reached a maximum shear load of 1024 kN for the vertical displacement of 75 mm. The maximum generated axial load on the bolt was 400 kN. Similar to the indented strand cable, there was a typical barrel and wedge adjustment axial load drop during the early part of the cable shearing process. This settlement occurred at 502 kN of vertical shear load and at the vertical shear displacement of 25 mm. No strand failure was detected during the shearing process as evident from the post- test dismantled cable bolt shown in Figure 8.

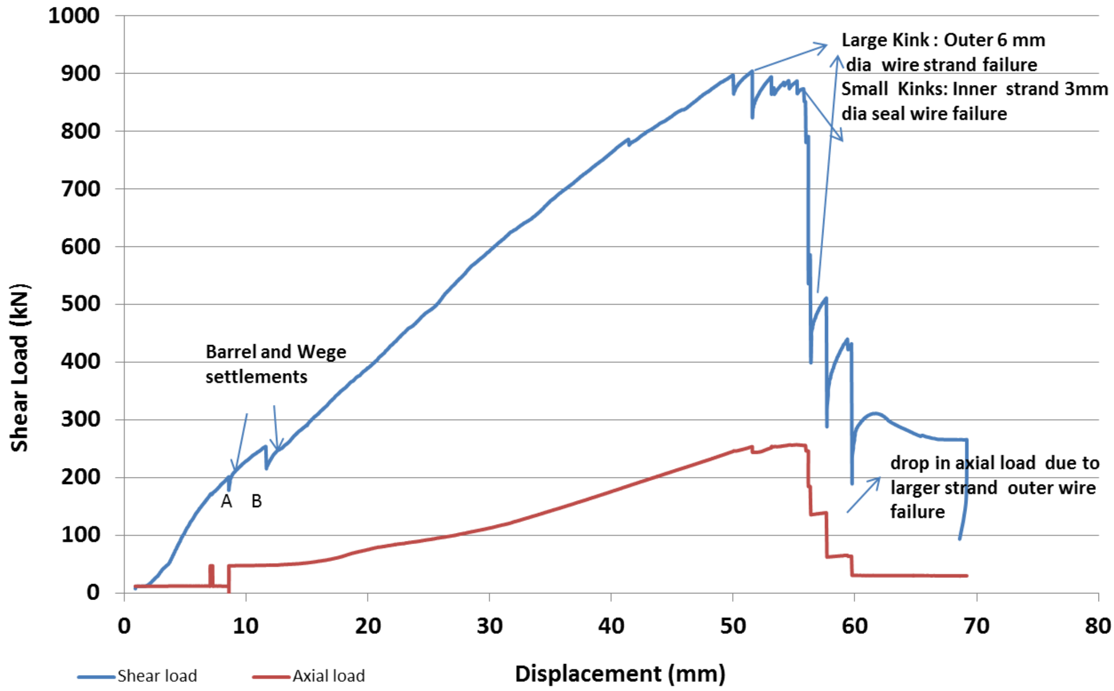

Figure 5 - Shear load and axial load versus vertical travel of the central block of the loaded double shear apparatus

(a) (b)

Figure 6 - (a) failed indented strand cable bolt and (b) concrete deformation around sheared section of the bolt

The maximum applied shear load on the UX-Strand (plain) cable of 1024 kN for vertical shear displacement of 725 mm was 13.8 % greater than the maximum shear load of 904 kN achieved from the IX strand (indented) cable. As can be seen in Table 1, the ultimate failure load of the UX-strand cable bolt of 495 kN is 70 kN more than the tensile strength of the IX -Strand cable bolt, which is an increase in the ultimate strength of 16.5% in favour of the plain strand cable bolt. Thus, the reduction of 70 kN in the ultimate tensile strength of the indented cable bolt may explain the reason as why the cable failed at much lower sharing load. This reduction in the indented cable strength was subsequently verified by tensile strength testing of cable's individual strands, which resulted in a drop in tensile strength of the indented strand by 10.0 %. Figure 9 shows typical profiles of load - elongation of both 5.5 mm plain and indent strands of cable bolts. The machining of the outer strands to create indentation may have a detrimental bearing on the strand strength, contributing to the reduced tensile and shear strength of the cable bolt. Therefore, it is fair to conclude that the strand manipulation for producing indentation may have affected the ultimate tensile strength of the intended cable bolt, as the overall cross sectional area of the indented cable bolt was reduced 13%. Finally, no cable rotation was observed in either the plain or indented strand cable bolt during the double shearing tests.

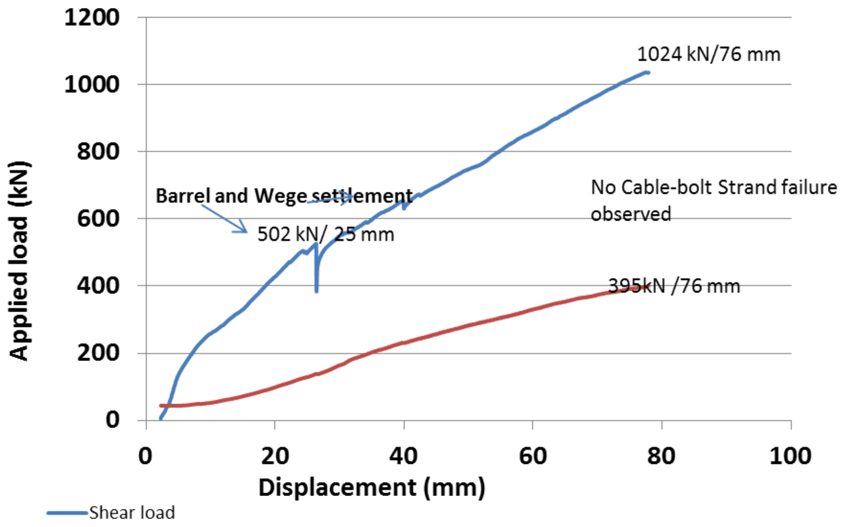

Figure 7 - Shear load and axial load versus vertical travel of the central block of the loaded double shear apparatus

Figure 8 - Post test plain strand cable. No strand failure

CONCLUSIONS

- The shearing strength of the cable bolt is influenced by the outer strand indentation, with the reduction in shearing strength to around 13.8%. However, the tensile strength failure of the individual strand resulted in a strength reduction of 12.8 %. Thus, indentation of the cable bolt's outer strand weakens the cable bolts tensile and shearing strength.
- All strands of the indented cable bolt failed post peak shear load. No strand failures were observed in the plain strand cable bolt tested in shear.

- All strands of the IX -Strand cable bolt failed in combined tensile and shear as demonstrated by the cup and cone failures of the failed cable section strands.
- The use of the laboratory based double embedment assembly for shear test as recommended by British Standard BS 7961-2 2009 is not a realistic way of evaluating the shear strength of cable bolts *in situ.*
- No cable rotation was detected in double shear testing of either plain or indented cable bolts.

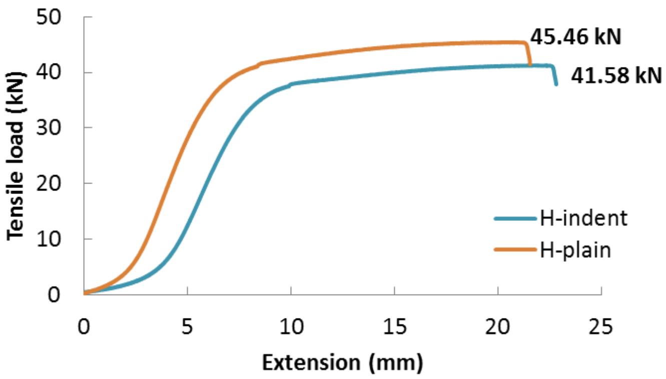

Figure 9 - Tensile load / elongation profiles of both plain and indent 5.5 mm strands of cable bolts

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