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Optimisation of the bolt profile configuration for load transfer enhancement

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OPTIMISATION OF THE BOLT PROFILE CONFIGURATION FOR LOAD TRANSFER ENHANCEMENT

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ABSTRACT: Both bolt profile shape and profile spacing (rib spacing) have been found to influence the bonding capacity of the grouted rock bolt. The bolt surface profile configuration has greater importance to rock bolt than the steel rebar used in civil engineering construction, because the rock bolt is subjected to greater dynamic loading than the steel rebar. The increased bonding capacity of bolts is important when supported ground is either heavily fractured, faulted or the supported ground is of soft formation, typically that of coal measure rocks. Past laboratory studies have identified the bolt profile spacing as of significant relevance to bolt resin rock bonding increase, however, no attempt has been made to determine the optimum spacing between the bolt profiles spacing. Accordingly, a series of laboratory tests were carried out on 22 core diameter bolts installed in cylindrical steel sleeve. The study was carried out by both push and pull testing. The push testing was carried out in 150 mm long sleeves while the pull testing was made in 115 mm long sleeves. Profile spacing tested include, 12.5, 25.0mm, 37.5 mm and 50 mm lengths. The profile spacing of 37.5 mm wide was found to provide the optimum bearing

INTRODUCTION

Rock bolts used for rock formation reinforcement differ in function from the steel ribbed rebar used in concrete reinforcement in building construction. The reinforcing effect of a grouted bolt is by the longitudinal and shear displacement in the rock mass. Thus the load transfer capacity of the bolt is governed by the shear strengths developed between the rock/grout and the grout/bolt. The bonding capacity of the bolt is in turn is influence by the bolt profile configurations. The profile configuration is defined by the rib profile shape, and height, angle of wrap and spacing or distance between the ribs.

Blumel (1996) was the first to report on the influence of profile spacing on load transfer capacity of the bolt. Figure 1 shows the results of a test of a particular rock bolt type with different distance or spacing between the ribs. The tests were undertaken in a specially constructed laboratory apparatus consisting of a 500 mm long steel pipe filled with concrete. The concrete had a central hole of diameter twice the bolt diameter. The bolt was anchored in the concrete cylinder using cementatious grout and the bolt pull-out tests were carried out with different displacement rates, applied to the bolt right from the installation. Blumel reported pull tests on different profile spacing, of 13.7 mm, 27.4 mm and 54.8 mm, and with pull-out tests values increasing with increased widening of the spacing respectively as shown in Figure 1. The tests were carried out with respect to time of loading up to 32 hours, with the pullout displacement rate of 0.72 mm/hr. The study clearly demonstrated that the pull-out force of the bolt differed greatly by varying the rib distance. No effort was made by the researchers to investigate the optimum spacing of the profiles for optimum bolt transfer capacity. Blumel, Schweiger and Golser (1997) reported on the final element modelling of the bolts with different profile spacings. Their study supported the experimental laboratory findings, which, as shown in Figure 2, clearly demonstrated that higher stresses with more significant peaks being developed in the case of the bolt with wider spaced ribs as compared to the small rib distance.

Aziz, and Day (2002) studied bolt profile spacing and load transfer conditions under constant normal stiffness (CNS) conditions under different confining pressures. The study confirmed the existence of changes in the load - displacement profiles with respect to bolt surface profile configurations. Moosavi, et al, (2005) also studied the profile configurations in cementatious grout, leading to similar conclusions. Aziz and Webb (2003) extended the study on profile configurations to include push testing of bolts installed in cylindrical steel tubes, 75 mm long and 17 mm in internal diameter. The tests were made using chemical resin instead of cement. Aziz and Jalalifar (2005 and 2006) extended this study to include both push and pull tests. Longer steel sleeve lengths greater than 75 mm were also used. 75 mm long steel sleeves were found to be of insufficient length to provide adequate number of profiles encapsulated in it to allow credible and meaningful test results. Aziz and Webb (2003) work concurred with the findings of the Blumel study on the effect of profile spacing on load transfer capacity of the loaded bolt.

There has been no reported attempts made to optimise the true bolt profile configurations for optimum load transfer capacity determination, and accordingly this paper represents the continuation of the work undertaken by the mining group at the University of Wollongong (UoW),and describes the laboratory testing of bolts in long steel sleeves which is aimed to address the profile spacing optimisation.

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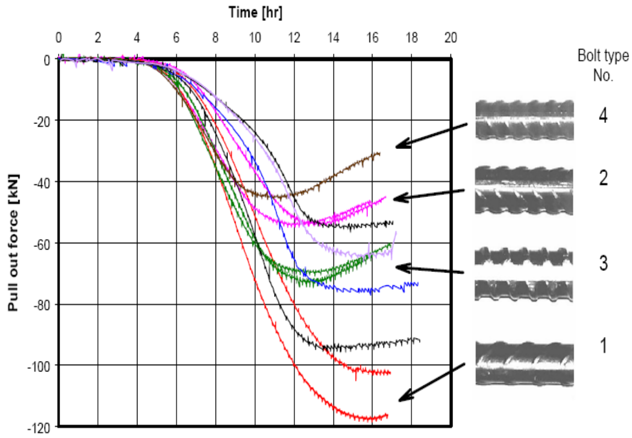


Figure 1 - The load / displacement profiles of different profile spacing bolts. Bolts were installed in a cementacious grout. The rate of loading being at 0.72 mm/hr

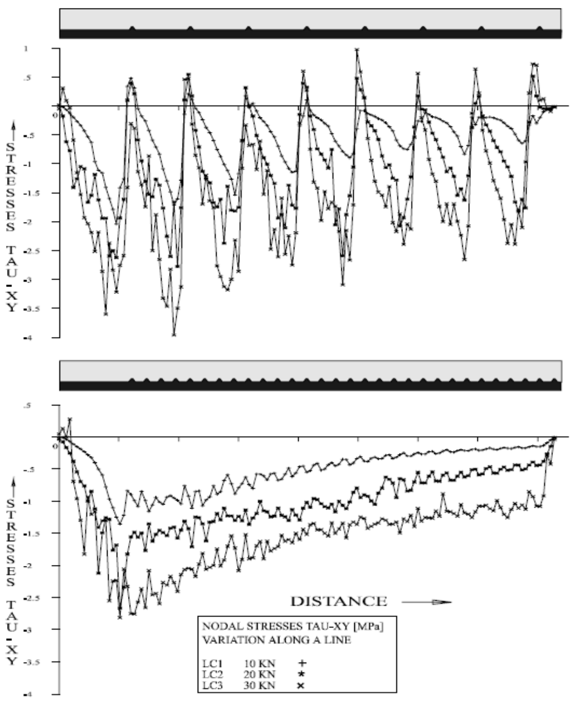


Figure 2 - Axial stress developed on bolts of two different spaced profiles

EXPERIMENTS

In order to obtain better understanding of the influence of increased profile spacing and bolt load capacity, two series of tests were carried out on bolts in cylindrical steel sleeves. In the first series of tests, bolts with different profile spacing were push tested in 150 mm steel sleeves, while the second set of tests were made under pull conditions using 115 mm steel sleeves.

Table 1 shows a summary of the profile dimensions for all the bolt types that were tested. Wider profile spacings were achieved by grinding various profiles. Bolts with widened spacings were labelled G1, G2 and G3 with one, two and three profiles removed respectively. The respective spacings were 25 mm, 37.5 mm and 50 mm. No tests are reported for Bolts T1 and T3 as the comparative tests were reported previously by Aziz, Jalaifar, and Conclaves (2006).

Table 1 - Profile configurations of various bolts

Bolt Type	T1	T2	T3	T2 Bolt Modified		
				G1	G2	G3
Profile Spacing (mm)	12.50	12.50	25.00	25.00	37.50	50.00
Profile Height (mm)	1.00	1.35	1.20	1.35	1.35	1.35
Average Profile Width (mm)	2.25	2.75	3.75	2.75	2.75	2.75
Profile Angle	22.5^{o}	22.5^{o}	22.5^{o}	22.5^{o}	22.5^{o}	22.5^{o}
Bolt Samples						

Push test

Figure 3 shows a general view of push testing of bolts of different profiles in 150 mm steel sleeves. The procedure for testing is described elsewhere (Aziz, Jalalifar, and Concalves (2006). The tests were made in a 50 tonne capacity servo-controlled Instron Testing Machine. The encapsulation medium was a reinforced polyester resin grout BPI Mix and Pour resin. The resin had curing time of 60 minutes. The UCS strength of the resin was in the order of 70 MPa after seven days, the shear strength was 16 MPa, modulus of elasticity of 12 GPa, and stiffness value after 14 days was around 75 kN/mm.

As can be seen from the test result in Figure 3, the loading capacity of the bolt increased with increased profile spacing. However, the highest loading capacity was achievable with profile spacing of 37.5 mm rather than 50 mm rib profile spacing. The loading of 37.5 mm spaced bolt was halted as the unencapsulated bolt section began to bend. For the indicated final level push load of 425.8 kN shown for 37.5 mm spaced profiled bolt (Bolt Type T2 G2) in Figure 3, this is 7% greater than the maximum load achievable of Bolt Type T2 G3 of 50 mm profile spacing, and is 16% greater than of Bolt T2 G1 of 25 mm profile spacing, as shown in Table 2. The loading capacity of T2 G2 bolt is 97.5 % greater than the original Bolt TypeT2, with 12.5 mm profile spacing. It should be noted that the differences between the load bearing capacity between the 25 mm profile spaced Bolt Types T2 G1 and T3 is attributed to the surface roughness of the Bolt Type T2G1, which was resulted from the removal of the profile from Bolt TypeT2. The effect of bolt surface roughness on the load bearing capacity of a bolt was previously reported by Aziz and Webb (2003). It is also equally true that the variations between the load bearing capacity between Bolt Types T2G2 and T2G3 could have been influenced by the increased surface roughness of Bolt Type T2G3, nevertheless, the bearing capacity of Bolt Type T2G3 is significantly higher than the T2G3.

Table 2 - Changes in the load capacity of different profile spaced bolts with respect to Bolt Type T2 in push testing (encapsulation length 150 mm)

Bolt Type	Profile spacing (mm)	Average. applied load (kN)	Increase in load with respect to Bolt Type T2 (%)
Bolt Type T2	12.5	215.6	-
Bolt Type T2 G1	25	365.9	69.7
Bolt Type T2-G2	37.5	425.8	97.5
Bolt Type T2-G3	50.0	398.2	84.9

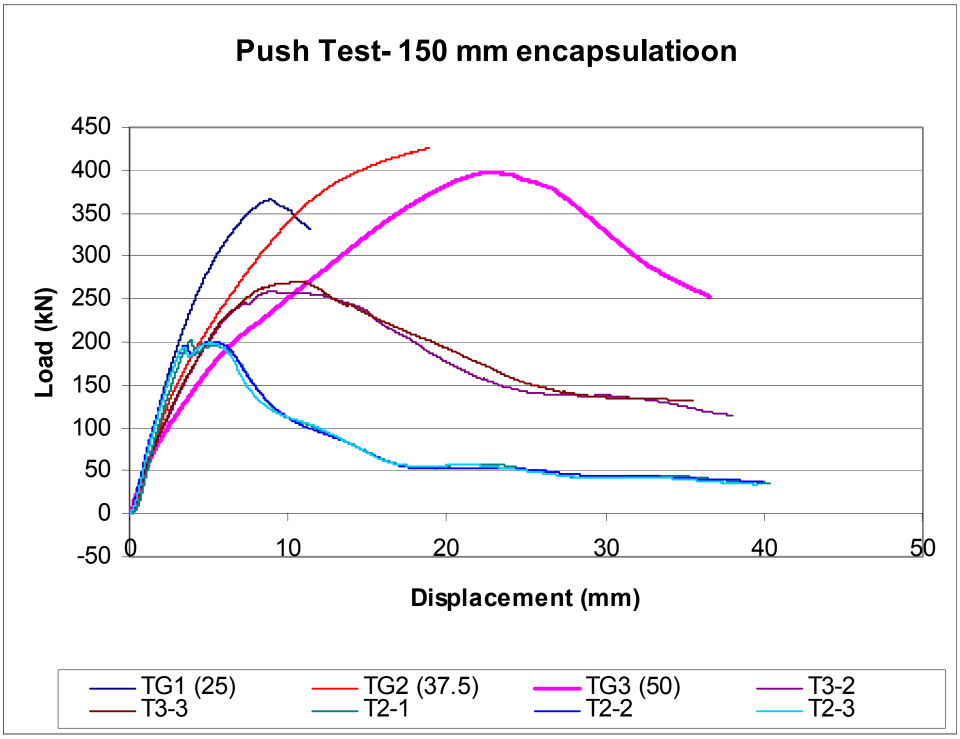


Figure 3 - Push test results of bolts with different profile spacing

Pull Test

A number of preliminary tests were made to study the bonding capacity in 150 mm sleeve encapsulation under pull-out conditions, and this was discontinued as the pull-out load exceeded the elastic limit of the steel rebar bolt. This was particularly true when testing bolts greater that 25 mm profile spacing. Noting that both Bolt Type T2-G1 and T3, with rib spacing of 25 mm, had the yield load of 250 kN and ultimate tensile strength of more 330kN.


Pull test – 150 mm encapsulation


Push test 150 mm encapsulation


150 mm steel sleeve

Figure 4 - Pull and push testing of bolts with different encapsulation length of 115 and 150 mm

Accordingly the next series of tests were carried out under pull testing conditions with the encapsulation length of the steel sleeve reduced to 115mm as shown in Figure 4. Figure 5 shows the load displacement profiles for four profile spacing of 12.5 mm, 37.5 mm and 50 mm respectively. Also included in Figure 5 are the load displacement graphs of 50 mm profile spacing prepared from Bolt Type T3. The difference between the profiles configurations of various bolts are as per described in Table 1.

As can be seen from Table 3, the bonding capacity or the peak load of the bolt with profile spacing 37.5 mm is, once again, greater than the 50 mm profile spacing. In this batch of tests the maximum pull out force was within the steel rebar yield load, thus there were no significant changes in bolt diameter, as would have happened in push testing.

When compared to the standard Bolt Type T2 (profile spacing 12.5 mm), all other bolts experienced an increase in the average maximum peak load capacity. The Bolt Type T3 with the modified profile spacing of 50 mm experienced an average increase of 41% in pull load of 215 kN against Bolt Type T2 load of 152.23 kN . Of more significance was the increase in loading capacity of both Bolt Types T2G2 and T2G3 respectively. The average peak load of the T2-G2 bolts with profile spacing of 37.5 mm was 69% greater than that of the standard Bolt Type T2. Similarly for the Bolt Type T2G3, with 50.0 mm profile spacing, there was an increase of 61% with respect to Bolt Type T2.

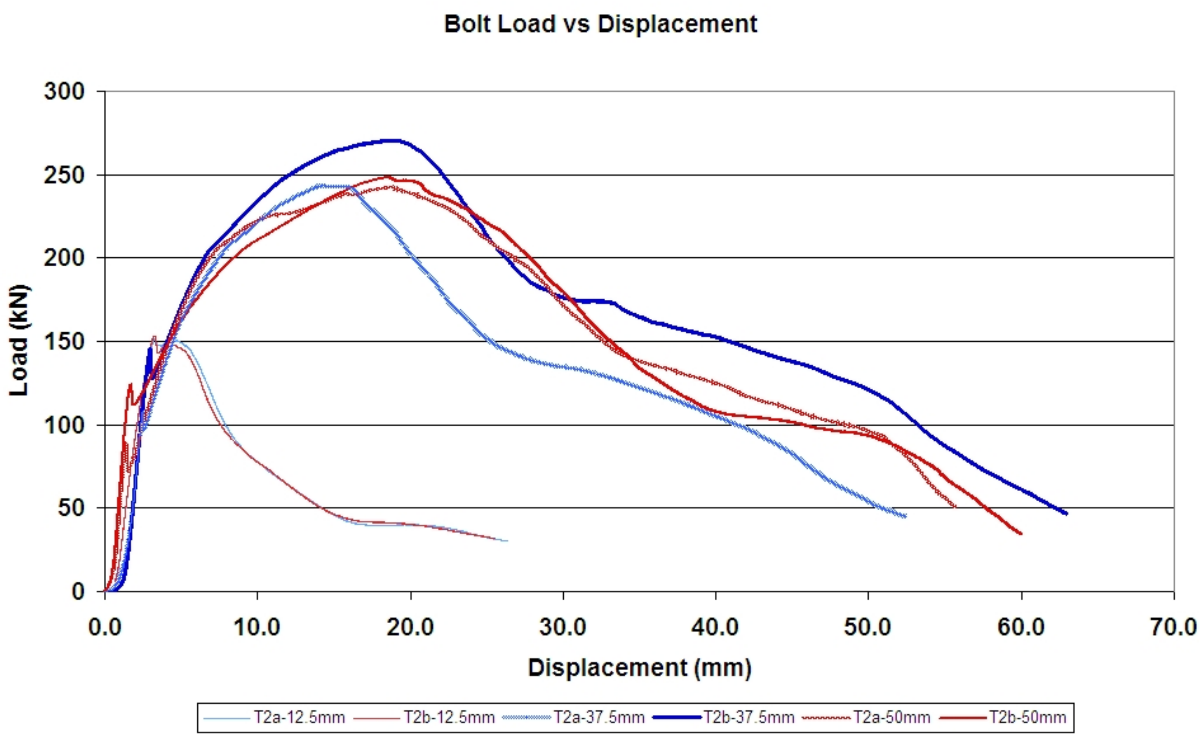


Figure 5 - Load displacement results of different configuration bolts in pull testing

Table 3 - Changes in the load capacity of different profile spaced bolts with respect to Bolt Type T2 in pull testing (encapsulation length 115 mm)

Bolt TypeFigure 3. Fresh air oxygen as measured by tube bundle	**Profile Spacing (mm)**	**Average Pull load (kN)**	**Change (increase) in load with respect to Bolt Type T2 (%)**
Bolt Type T2	12.5	152.23	-
Bolt Type T3 G1	25	215.23	41
Bolt Type T2-G2	37.5	256.55	69
Bolt Type T2-G3	50.0	244.72	61

FUTURE WORK

Additional tests must be undertaken by pull testing in the laboratory concrete block, the field test, double shearing test and dynamic drop test.

Preliminary double shearing tests carried out by the authors have lead to inconclusive results. These tests were made in the same share box as that reported by Aziz, Pratt and Williams (2003). Suffice to say that the shearing characteristic of the wider profile bolts with spacing greater 25 mm and greater, were of similar characteristics as that reported by Aziz, Pratt and William. Future tests will be carried out in a much larger shear box, as shown in Figure 6.

The load drop test (Figure 7) is aimed to subject the bolt to impulsive dynamic loading. The objective is to examine the performance of different bolts under different dynamic loading conditions. The dynamic shearing characteristics will be examined under a range of impulse loading conditions by varying the drop height of a 600 kg anvil onto a test sample in a double shear box, thus enabling variable amounts of impact energy to be imparted to the test specimens.

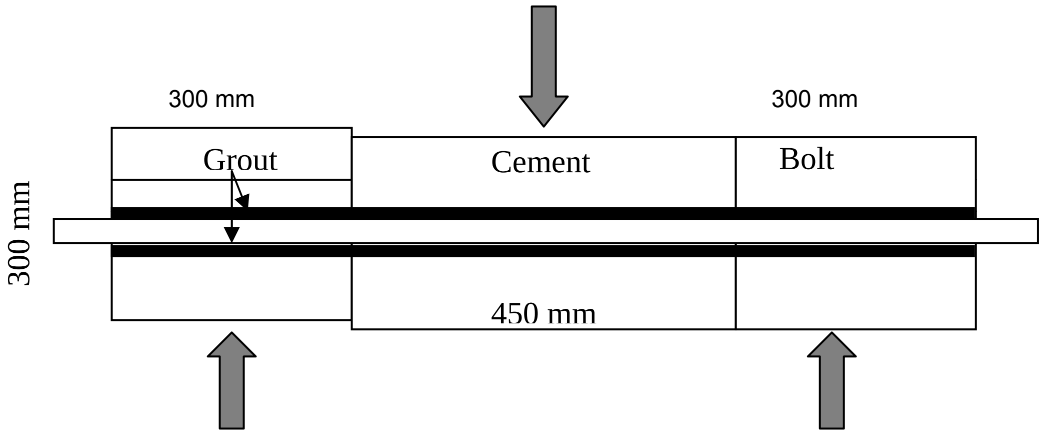
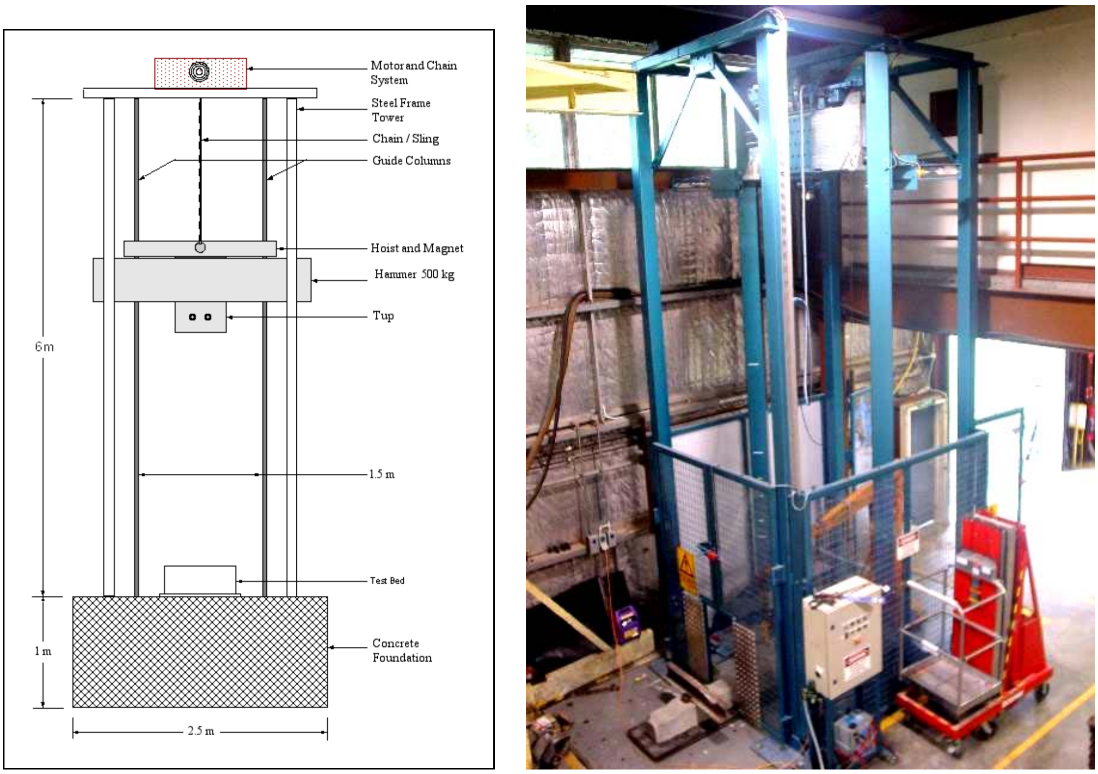


Figure 6 - Large double shear box



Schematic Figure 7 - Large capacity impact load test facility at UoW

CONCLUSIONS

It is abundantly clear from this study and from overseas that, the bonding capacity of the bolt increases with increased profile spacing. The profile spacing 37.5 mm was found to be the optimum spacing width with the particular type of bolt (with given profile orientation and shape).

For the wider spaced bolts to be assured of its performance in reality, tests must be extended to pull testing in the field as well as carrying out double shearing tests to examine the effect of latter forces in shear.

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