
AN UPDATE OF ROOF BOLT RESEARCH AT THE UNIVERSITY OF WOLLONGONG

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ABSTRACT: The influence of surface profile on load transfer mechanisms of bolts has been studied under both the constant normal stiffness (CNS) and constant normal load (CNL) conditions. Testing under CNS condition was conducted in a specially constructed constant normal stiffness shearing apparatus, whereby the flattened surface of a bolt section was pulled against the image of cast resin sample under constant stiffness conditions. Testing under CNL conditions included the conventional pull testing of an encapsulated section of bolt anchored in a borehole, and the short encapsulation push test.

The conventional pull testing involved pull testing of three different profiled bolts in three different diameter holes. The pull tests were carried out both insitu and in the laboratory. Parameters examined, in addition to bolt surface profile, were the resin annulus thickness and the effectiveness of resin mixing in the hole.

The credibility of push testing, in short steel cylinder sleeves, was examined by pulling the bolt out of the cylindrical sleeve instead of pushing. Also tested in short sleeve, was the possibility of changing the load transfer capability of a bolt by changing its surface profile.

A numerical simulation study has recently been incorporated to enhance the current programme of research carried out at the School of Civil, Mining and Environmental Engineering, The University of Wollongong. The numerical study included the modeling of both the short encapsulation push/ pull test as well as shear stress simulation across joints. The conclusions drawn were that the bolt surface profile is an important parameter affecting the load transfer capacity of the bolt/rock interface, that the anchorage strength of resin encapsulation is influenced by the effectiveness of resin mixing, and the annulus thickness, and the short encapsulation push test underestimates the peak shear load and peak load displacement.

INTRODUCTION

The following programme of research is currently ongoing at the School of Civil, Mining and Environmental Engineering, University of Wollongong:

- Examination of bolt resin shear failures under CNS conditions;
- Load transfer mechanism studies by conventional pull tests, to include pull out testing of bolt with encapsulation length up to 300 mm. This type of study is carried out both in the laboratory and in the field. Different bolt surface profiles were examined;
- Push /pull testing of the bolt encapsulated in a short steel sleeve;
- Double shear testing of bolts, with 1.20 m long bolts installed in a three-piece concrete block, subjected to shearing load;
- Modeling of bolt shear failure in both short encapsulation and double shearing tests; and
- Bolt corrosion with respect to stress corrosion cracking. A purpose-designed rig, that allows tests to be conducted on bolts under both tension and torsion conditions.

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The latest of the research findings are presented with different methods listed above. The study on shearing under CSN conditions reported by Aziz, (2002), Aziz and Dey and Indraratna (1999), was further extended to include testing under triaxial conditions. However, the study on short Encapsulation test, reported, by Aziz and Webb (2003a) is extended to include tests by pulling of the bolt out of steel cylinder. Additional studies include bolt technology appraisal by numerical modeling, laboratory, and fieldwork and are the subject of this presentation.

The modeling of the double shearing tests, though reported here, is dealt in a separate paper in this proceedings by Jalalifar, Aziz and Hadi (2004).

CONVENTIONAL SHORT ENCAPSULATION PULL TEST

Laboratory Test

The laboratory experimental work was carried out in a purpose built testing rig facility pictured in Figure 1a. The rig consisted of a double deck steel frame structure. The upper deck carried a drilling medium of a block of rock or concrete and an overhead-lifting crane (not shown in the figure) used for lifting and placement of the drilled medium. A hydraulic drilling rig, positioned beneath the drilled concrete block, was adapted from a continuous miner.

The high strength concrete block had a 1.0m^2 base area that tapered to 0.9m^2 area at the top, and an overall height of 1.2m. Figure 1b shows the general arrangement for pull testing of the bolts. The hydraulic ram had a maximum capability of 30 tonnes and was powered with a two-stage 'Rodgers' hydraulic pump. The load applied to the bolt was measured using a hollow load cell. A Linear Variable Differential Transducer (LVDT) was used to measure the bolt axial displacement during the pulling process.

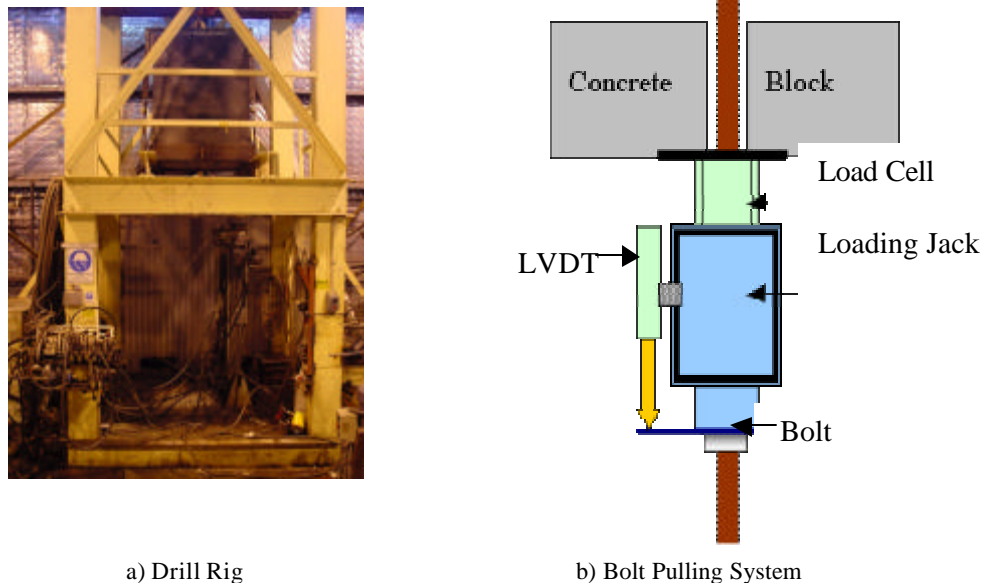





Fig 1 – Laboratory drill rig and bolt pull test arrangement

The process of bolt installation in the concrete block consisted of, firstly drilling the desired borehole diameter (e.g. 27mm, 28mm or 35mm) to a pre-determined depth of 500 mm. The first 200 mm section of each hole was then reamed using a significantly larger drill bit. This was necessary to allow deeper anchoring of the bolt in the concrete block, thus avoiding premature cracking of the block during the loading process, as had occurred on several occasions previously. Also, the reamed section allowed any excess resin to fall out of the hole thus preventing over-encapsulation. All drill holes were checked for rifling to permit an effective concrete /resin bonding as shown in Figure 2.

Table 1 - General specifications of the bolts

	T1	T2	T3
Bolt core dia.(mm)	21.7	21.7	21.7
Profile centres	12.00	12.50	25
UTS (kN)	330	340	340
Yield Pt load (kN)	250	256	247
Profile height (mm)	0.65	1.40	1.25
Profile angle (°)	21.5°	21.5°	21.50°
Profile top width (mm)	1.50	2.00	2.50
Profile base width	3.00	4.00	5.00
Bolt configuration			

**Fig 2 - Rifled drill hole**

Initially the encapsulation length was 300 mm, and this was later reduced to 260 mm as the pulling force exceeded the pulling capacity of the jack and was well above the elastic yield point of the bolt. All the bolt types used in the test had the ultimate tensile strength about 34 tonnes and yield strength around 25 tonnes. Other details of the bolts used in both investigations are shown in Table 1. For obvious reasons all the bolt types were given identification designations.

A total of 55 bolts were installed in three different borehole diameters of 27, 28 and 32 mm respectively (It should be noted that the third hole size diameter at the field study was 32 mm instead of 35 mm). The tested bolts were Bolt Types T1, T2 and T3. 45 bolts were installed in the concrete block using resin cartridge and the remaining 10 bolts were installed with PREMIX resin (known as Mix and Pore 'P1' Resin). Premixing involved mixing the resin in a container and pouring it into the hole around the bolt in the inverted concrete block.

Field Test

Field tests were carried out at the intake side of an underground local coalmine in the Illawarra Coalfield of NSW, Australia. All the holes were drilled in medium to coarse sandstone, which can be described as a competent formation. Three hole sizes were used with anchorage lengths being maintained at 300mm. The holes were initially drilled at 500 mm in length and the first 200 mm length was then reamed to 35 mm. A total of 36 bolts were installed in three different bolt diameters of 27, 28 and 32 mm respectively.

RESULTS AND DISCUSSIONS

Table 2 shows the average peak loads and peak displacement of all three bolts tested in the laboratory and in the field using different diameter holes. Figures 3 a, b and c show the laboratory results of the pull tests carried out on three different bolts and in three different diameter holes. Figures 3 d, e, and f show the field test results of the peak load and displacement values of similar type bolts in three different borehole diameter holes. Clearly the methodology of resin encapsulation application had some influence on bolt anchorage performance. The pull out anchorage loads for premix encapsulation far exceeded those obtained from cartridge types irrespective of bolt type and annulus thickness.

Table 2 - Summary of average results

Bolt	Hole dia (mm)	Average peak load		Displacement at peak load		Average shear stress		Shear Stiffness	
		(kN)		(mm)		(MPa)		KN/mm	
		Lab	Field	Lab	Field	Lab	Field	Lab	Field
T1	27	246	190	8.05	25.1	13.9	9.30	50.0	35.0
T1	28	167	154	5.75	9.4	9.5	7.53	47.0	20.0
T1	32	>300*/ 66**	75**	3.54	8.9	2.8	3.67	-	-
T2	27	251.7	229	6.29	14.5	14.2	11.19	46.0	53.0
T2	28	235.8	155	7.04	8.0	13.3	7.58	38.0	22.0
T2	35/32	> 300*	(68)**	-	-	>16.9*	3.3	-	-
T3	27	>300	251	15.56	42	17	12.27	53.0	47.0
T3	28	252.8	179	12.63	12	14.3	8.75	46.0	17
T3	32	>300*	(16)**	-	3.0	>16.9	0.78	-	-

NB: * - Cartridge resin encapsulation , ** Premix resin encapsulation

Load –displacement

The laboratory results shown in Figure 3 were obtained from 260 mm long encapsulation, whereas the in situ field data were from 300 mm long resin encapsulation. The results from two different testing conditions have produced near similar trends. As expected, the peak pull force for widely spaced profiled Bolt Type T3 occurred at greater displacement than Bolt Types T1 and T2 as indicated also in Table 2. Such behaviour is similar to that obtained from both the CNS test (Aziz and Dey 1999) and short encapsulation test (Aziz and Webb 2003 a, and 2003b). In particular, the displacement at peak load was greatest for Bolt Type T3 bolt. Bolt Type T2 followed this, in most cases, and the least displacement was for Bolt Type T1.

The following can be deduced from both the laboratory and field test results as listed in Table 2 above:

- 1) The peak load displacement varied according to the bolt profile configuration. There was very little difference in displacement at peak load between two equally spaced Bolt Types T1 and T2 profiles, however the displacement was greater in widely spaced Bolt Type T3.
- 2) This finding was in agreement with previous reporting by both Aziz (2002) Aziz and Webb (2003a), and Aziz and Webb (2003 b).
- 3) For all three bolt Types, the average peak pulling force values and displacement at peak load was highest in the 27 mm diameter holes. This was followed by the 28 mm holes and with the least values being obtained in 35 mm holes. However, the variation in peak loads with respect to borehole diameter did not hold when the bolts were anchored with pre-mix resins encapsulation.
- 4) Premix resin encapsulation was found to be superior in performance to the cartridge type. This is obviously clear from the results of the tests in the laboratory for all three bolts and as evident Figure 3c.
- 5) The reduced performance of pull out force with increased annulus thickness was considered to be attributed to insufficient resin mixing leading to excessive gloving, which is discussed later
- 6) Rifling of the hole (Fig 1) prevented the failure along the resin /concrete interface.

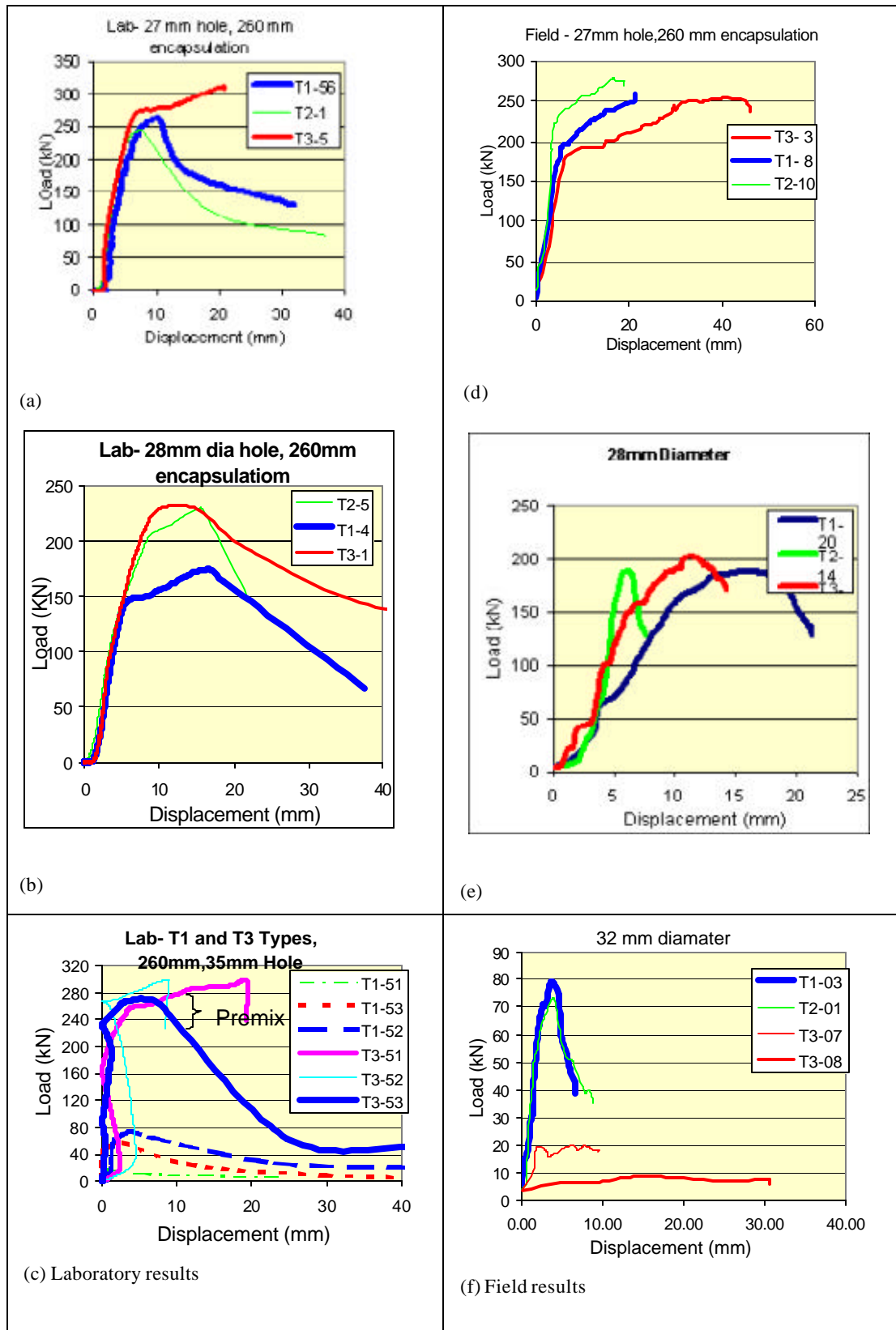


Fig 3 - Laboratory and field test results for different bolts

Encapsulation Annulus Thickness

Figure 4 shows the load displacement profiles of Bolt Type T1 in different diameter holes obtained from both the laboratory and field tests. Both tests clearly demonstrated that the increased resin annulus thickness had an adverse influence on the bolt performance. A closer examination of the results in Figures 3 c and 3 f, revealed the same pattern of results for bolt Type T1 and T3 respectively, but although at different rates. No tests were made on Bolt Type T2 in 35 mm holes.

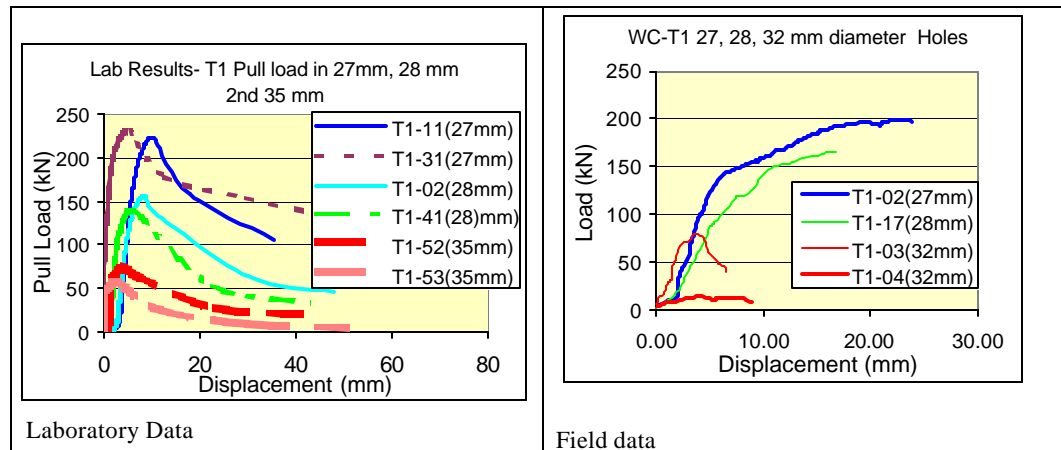


Fig 4 - Load-displacement of Type T1 Bolt in different annulus thickness encapsulation

No differences in performances were observed in the laboratory tests when all three-bolt types were installed in different diameter holes using premix resin encapsulation. As can be seen in Fig. 3 c, the peak pulling load of premix resin installed bolts were around 300 kN. The results demonstrated that increasing annulus thickness of the encapsulation was due to the quality of resin mixing and the degree of gloving formation and variations in resin encapsulation thickness. Bolts with higher and closer spaced profiles are likely to provide better mixing capability of the resin encapsulation than the bolts with lower and wider spaced profiles. This is because the high and closer spaced profiles (eg. Bolt Type T2) may generate more effective spinning force, allowing better shredding of the resin cartridge sleeve than the bolts with wider and lower profiles.

In an endeavour to examine the role of increased annulus encapsulation thickness on resin anchorage strength, a comparative push test was made using two different encapsulation thicknesses. As can be seen in Figure 5, that there was a dramatic reduction in pulling force between the two-encapsulation thicknesses. In both cases the same profile type of bolt was used.

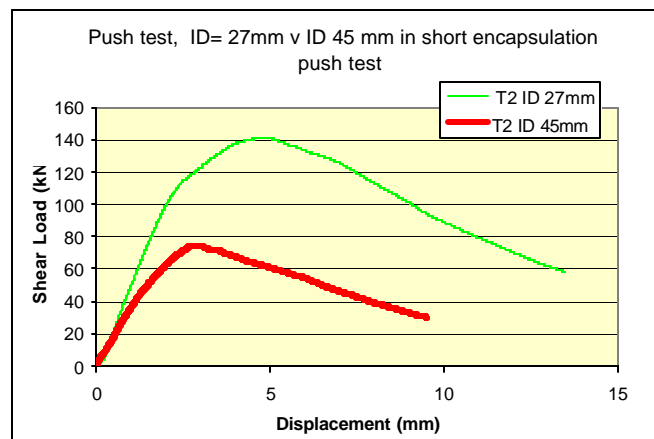


Fig 5 - Comparison of push tests in different internal diameter steel sleeve

PUSH/PULL TESTING IN STEEL SLEEVES

Concern has been expressed about the methodology of testing, in which the bolt is pushed out of the steel tube rather than being pulled. In reality the installation and subsequent performance of bolts in -situ results in the bolt being in tension and sometimes in tension and shear. There will be a general reduction in bolt cross section as a result of bolt tensioning, causing premature bolt resin surface contact failure and loss of grip. Scepticism has been expressed on the role of bolt profile configuration and its influence on load transfer capacity of bolt /resin interface. Accordingly the following two sets of tests were undertaken;

1. Increasing the rib profile spacing of Bolt Type T2 by filing away the alternative ribs
2. Pull testing of the bolt from the steel sleeves instead of the conventional push test

Profile spacing: Figure 6 shows the results of profiles of the Bolt Type T3 and Bolt Type T2 with its alternate ribs being filed away. As can be seen, the removal of alternative ribs from the bolts has increased peak load displacement, which is as close to that of Bolt Type T3. It is unlikely the profile configurations would fit to each other because of different profile spacing and profile height as shown in Table 1. However the results clearly demonstrate the influence of the profile configuration on load transfer mechanism relationships. This finding should be taken into consideration for future designs in different ground conditions, see Aziz and Webb (2003a, and 2003 b), and Aziz, Dey and Indraratna (1999).

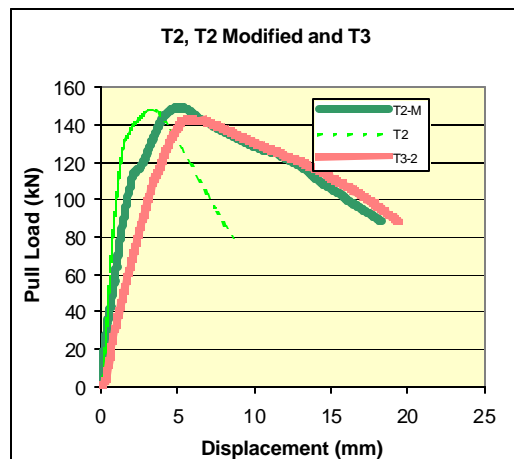


Fig 6 - Load displacement profiles of Bolt Types T2 and T3 and a modified Bolt Type T2 with alternative profile removed.



Fig 7 – Pull tests arrangement

Bolt pulling through the steel sleeve: Figure 7 shows the test set-up for pulling a bolt out of 75mm steel sleeve, and Figure 8 shows the pull test load /displacement results of bolt Type T2.

Table 3 shows the comparative test results of pull and push tests. Both push and pull test samples were prepared from the same premix resin batch. Also included in the table are the average values of push tests carried out by Webb (2001).

There were some variations in the values from different bolts. The difference between the average push and pull test results for both Bolt Types T1 and T2 were in the range of between 8 and 11 % respectively. Further research is continuing to examine other profiled bolts

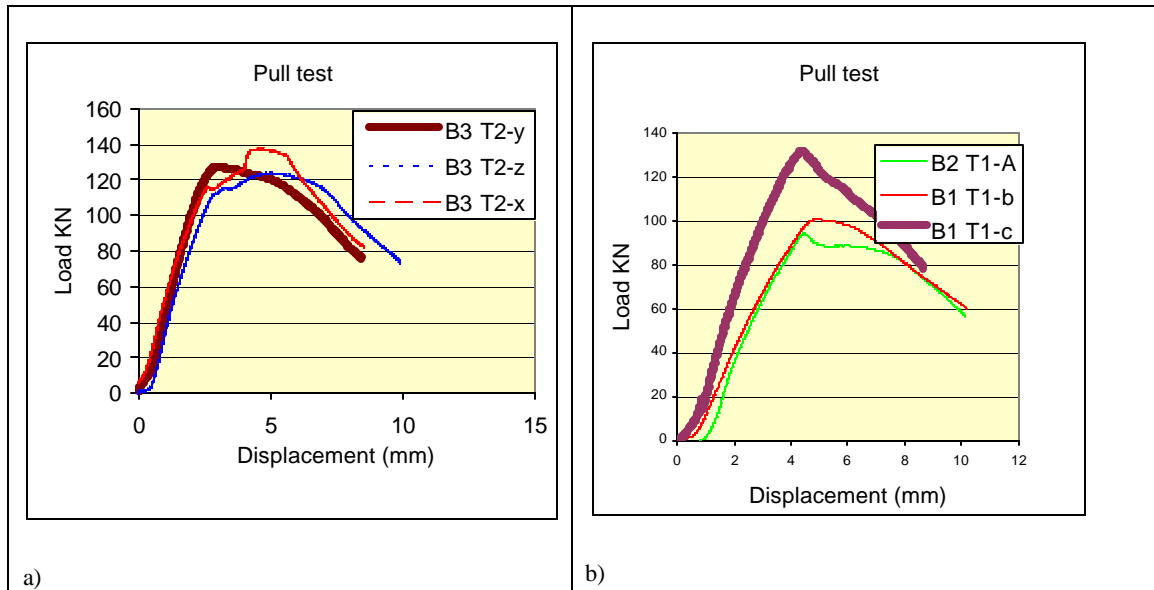


Fig 8 - Pull test results for Bolt Types T1 and T2

Table 3 Data from push and pull tests

Bolt Type	Av peak push load and SD (kN)	Av Peak pull load and SD (kN)	Diff (%)	Ave peak Load displacement Push and SD (mm)	Ave peak load displacement and (SD) (mm)	Diff (%)
T1	130.7 (± 10.85)	120.06 (± 16.4)	8	3.55 (± 0.63)	4.60	13
T2	140.31 (± 6.0)	129.4 (± 6.95)	9	4.85 (± 0.82)	7.92	39

CONCLUSIONS

Both programmes of the experimental study have led to the following conclusions:

- 1) Bolt surface profile configuration play a dominant influence on the load transfer capacity of the bolt. The high and profile spacing affect the level and sustainability of the transfer mechanism. Wider spaced profiled bolts maintains peak pull load at greater displacement than the closely spaced bolts. Also post peak load tapers off gradually as compared to narrow spaced and low height profile bolts.
- 2) Changing the profile configuration of the bolt caused a change in load transfer capacity of the bolt
- 3) The strength of resin encapsulation is influenced by the annulus thickness of encapsulation. Also affecting the strength is the quality of resin mixing and degree of gloving formation.
- 4) Premix resin encapsulation was found to be superior in performance to the cartridge type resin.
- 5) The methodology of removing the bolt in short encapsulation tests has an influence on the pulling results. There was a difference of 10% between the bolts pushed and pulled out of short encapsulation tests.

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