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DOUBLE SHEAR TESTING OF BOLTS

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ABSTRACT: Double shear testing was carried out on fully grouted and axially tensioned bolts installed in two different types of three piece concrete blocks. The purpose of the study was to examine the behaviour of reinforced bolts in shear under different axial loading conditions. A total of 22 bolts were tested using three common types of bolts used in Australia. The differentiating factor in bolt selection was the surface profile configuration, and the role of such configuration on the load transfer characteristic of cement/resin and bolt interactions. The influence of different tensional loads on the load transfer characteristics of bolts was also examined. The study showed that the medium strength and the axial tensional load influenced the level of shear load. Higher bolt profile configuration was least affected by the increased axial tensional load changes. There was no clear relationship between the vertical displacement at elastic yield point and each of bolt type, applied axial tensional loads and the medium strength. However, the shear loads were found to increase with increasing tensional loads and that the bolt profile configuration had influenced the shear load.

INTRODUCTION

The shear behaviour of reinforced joints and bedding planes has remained the subject of research for several decades particularly in geotechnical engineering. Bjurstrom (1974) was one of the early pioneers in the field. Based on his studies on granite specimens reinforced by fully grouted steel bolts, Bjurstrom reported that, the bolt failure characteristics were dependent upon the angle between the bolt and the joint planes, and that the bolt failure in tension occurred when the angle was less than 35°. He also suggested that the shear strength of such rock was dependent on, the shear resistance due to reinforcement effect, shear resistance due to the dowel effect and shear resistance due to the friction of joint of the host medium. Hass (1981) working on reinforced limestone specimens, with artificially cut joints, has concluded the orientation of rock bolts relative to the shear plane had the shear resistance offered by the bolt. Hass also stated that the shear strength of a bolted joint was found to be the sum of the bolt contribution and the friction resulting from the normal stress on the shear plane. Ferrero (1995) proposed a shear strength model for reinforced rock joints and suggested that the overall strength of the reinforced joint could be attributed to the combination of both the dowel effect and the incremental axial force due to the bar deformation. Ferrero's analytical model was applicable to the bolts installed perpendicular to the joint plane in stratified bedding planes. Dight (1982) conducted an extensive study of the behaviour of a fully grouted bolt in shear, He developed a theoretical model with bolt failure in shear and was able to verify his model with experimental results.

There has been very little interest in examining the influence of the bolt surface profile to the joint or bedding interface reinforcement. Accordingly, a laboratory based study was undertaken to examine the effect of profile characteristics and configuration on load transfer mechanisms between rock/resin /bolt. Three well known bolt brands were selected for the investigation, and for the sake of unanimity they were given different designations.

EXPERIMENTAL PROCEDURE

Block Casting

Double-jointed concrete blocks were cast for each double shearing test. Two different strengths of concrete blocks were cast, 40MPa and 20MPa strengths to simulate two different strength rocks.

Once mixed the concrete was poured into greased wooden moulds measuring 600mm x 150mm x 150mm which were divided into three sections separated by two metal plates. A length of plastic conduit 24mm in diameter was set through the centre of the mould lengthways to create a hole for the bolt. The concrete was left for 24hrs to set and then removed from the moulds and placed in a water bath for a period of 30 days to cure. The plastic conduit

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was removed from the centre of the blocks and the hole was reamed to 27 mm diameter, ready for the bolt installation.

1400 mm long bolt, threaded 100 mm on both ends was then fixed in the concrete specimen using Fosroc Chemfix PB1 Mix and Pour grout resin. Care was taken to install all the bolts in their respective concrete blocks with uniform profile /flash orientation. The bolted blocks were left for at least half an hour to allow the resin to cure before moving them for the place of storage. Most bolted specimens were left for days or up to few weeks before being tested.

The concrete/bolt assembly was then mounted in a steel frame shear box fabricated for this purpose. A base platform that fitted into the bottom ram of the Instron Universal Testing Machine, capacity 50 kN, was used to hold the shear box. Steel blocks about 55mm thick were placed beneath the two outer concrete blocks to allow for centre block vertical displacement when shearing load is applied. The two outer ends of the shear box were then clamped tightly with the base platform to avoid toppling of the blocks during shear loading. A predetermined tensile load was applied to the bolt prior to shear loading. This acted as a compressive/confining pressure to simulate different forces on the joints within the concrete. The three nominated tensions were 20KN, 50KN and 80KN. Axial tensioning of the bolt was accomplished by tightening simultaneously the nuts on both ends of the bolt. The applied axial loads were monitored by two hollow load cells mounted on the bolt on either side of the block. During testing, load-cell readings were taken every 20 kN at 0.04 sec /minute loading rate. The outer sections of the shear box remained fixed as the central block was pushed down.

A total of 28 bolts and concrete specimens were tested in the combinations shown in Table 1. Bolt type T3 was rather under-represented due to time constrain. Figure 1 shows a typical view of the assembled shear box unit in a testing machine and sketch of deformed bolt together with a number of post testing deformed bolts and sketch of deformed bolt together with a number of post test deformed bolts.

Table 1 – Experimental Schedule indicating the number of samples tests per bolt type

	20MPa Concrete			40Mpa Concrete			***Total***
Bolt Type	20kN	50kN	80kN	20kN	50kN	80kN	
AX	2	2	2	1	2	2	***11***
AXR	2	2	2	2	2	2	***12***
JAB	1	0	1	1	1	1	***5***
Total	***5***	***4***	***5***	***4***	***5***	***4***	***28***

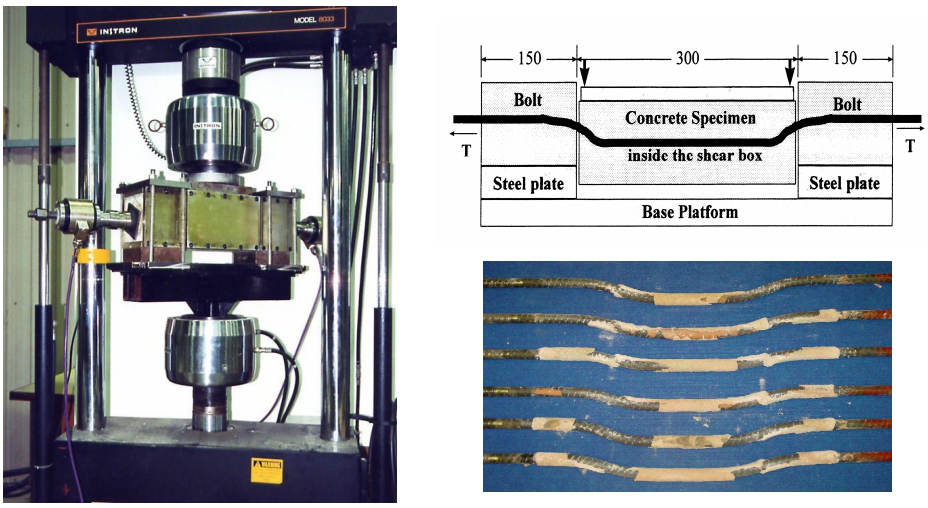

FIG. 3 - Photograph of tested sample in Instron testing machine and sketch of deformed bolt together with a number of post testing deformed bolts

RESULTS AND ANALYSIS

Shear Load and Shear displacement (deflection)

Figure 2 shows shear load and shear displacement (deflection) of bolts tested in both 20 and 40 MPa strength concrete and under different tensile loading conditions respectively. The shear load increased at the initial stage of loading until the elastic yield point was reached. The rate of loading began to decrease with increased shear displacement, Table 2 shows the shear load and shear displacements at elastic yield points for various cases. = Figure 3 (a-f) shows the comparative shear load and vertical displacement profiles in both 20 and 40 MPa concrete medium respectively.

Table 2-yield point shear load values for different bolts under differing environment.

Concrete strength (MPa)	Tensile load (kN)	Type 1 Shear Load at y/ point (kN)	Type 1 Shear displace. at y/point (mm)	Type 2 Load at Y/ point (kN)	Type 2 Shear displace. at y/point (mm)	Type 3 Load at Y/point (kN)	Type 3 Shear displace. at y/point (mm)
40	20	180	2.79	240	5.84	240	3.88
40	50	200	4.59	240	4.86	300	5.21
40	80	240	3.37	240	4.38	180	3.58
20	20	100	4.89	160	8.86	80	6.51
20	50	150	5.86	160	4.64	-	-
20	80	180	5.84	160	4.69	180	4.61

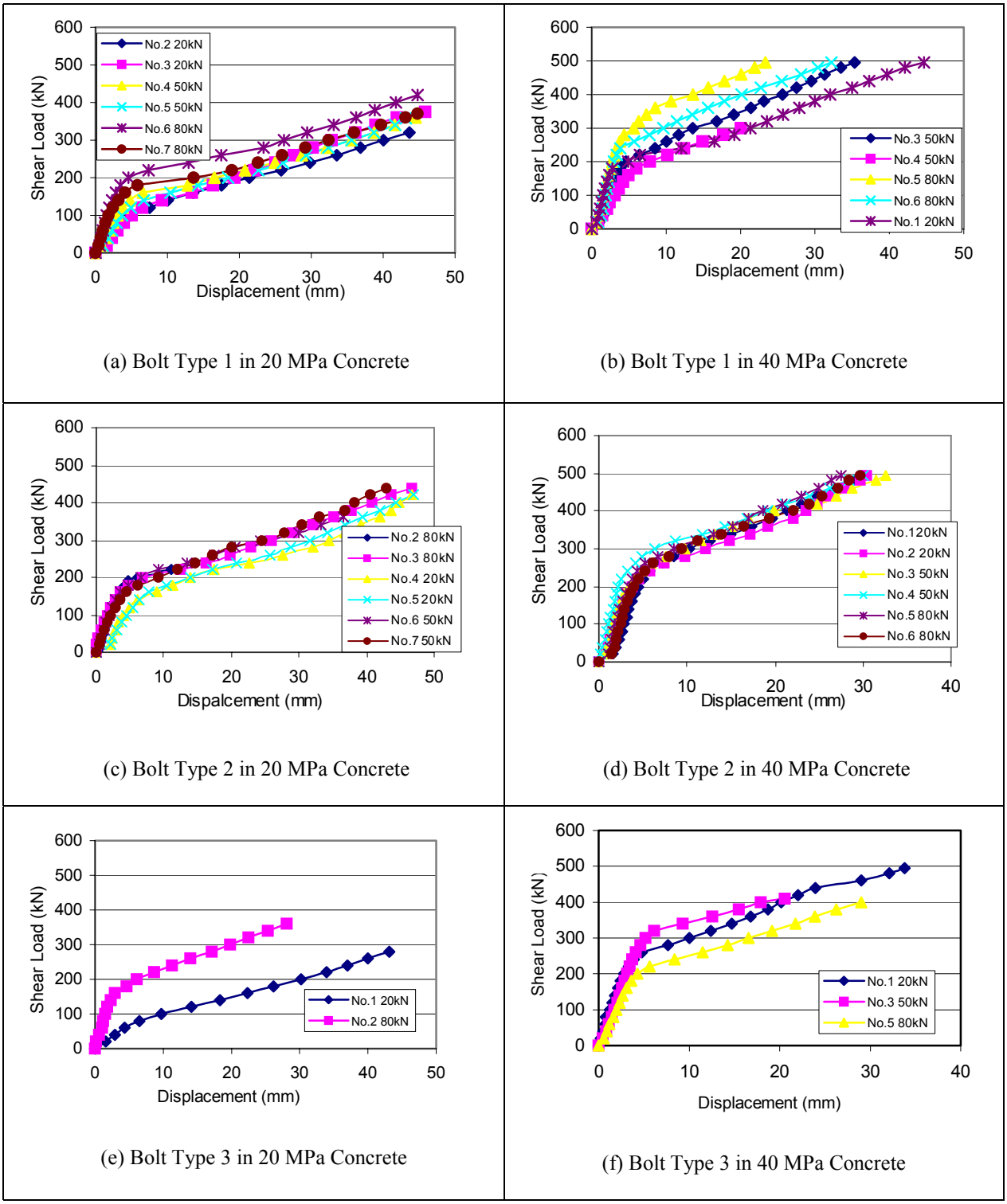

FIG. 2 - Shear load and shear displacement of bolts tested in both 20 and 40 MPa strength concrete and under different tensile loading conditions respectively

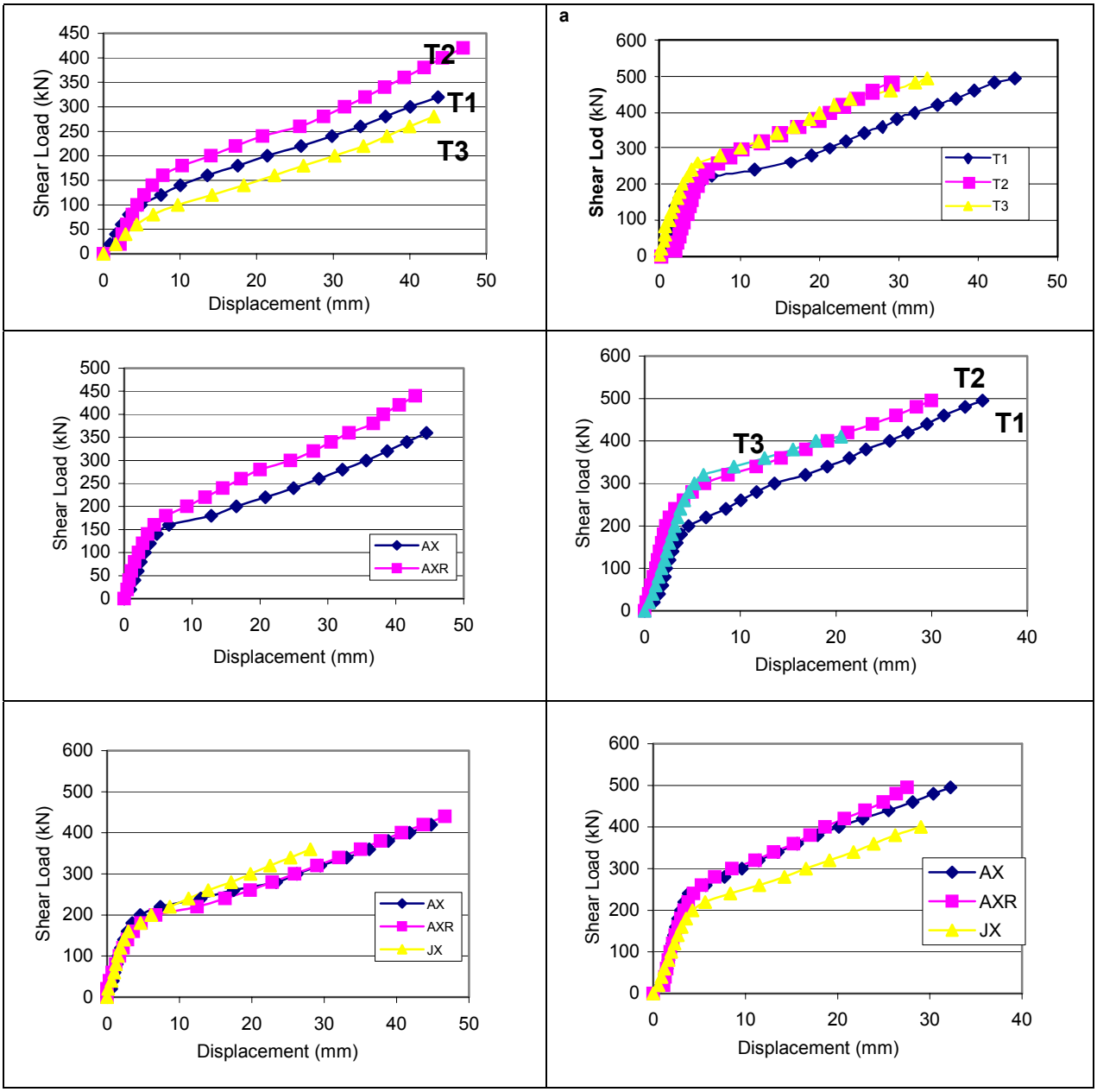

FIG. 3 - All bolt shear load and vertical displacement profiles in both 20 and 40 MPa concrete medium

The following can be noted from the shear load and deflection graphs:

1) The shear load of the bolt increased with increasing bolt tension for Bolt Type 1. There was almost no change in shear load in Bolt Type 2 and ironically there was a decline in shear load in Bolt Type 3. As shown in Table 1, only one test was made per test condition for Bolt Type 3, while two tests were made for other two bolts per given condition.
2) The strength of the medium has influenced the shear load level but not the trend. Shear load values for all bolts were generally less in 20 MPa concrete medium in comparison to the shear load values of bolts tested in 40 MPa concrete.
3) In general the shear displacement at elastic yield point was not consistent irrespective of the concrete type and the axial load. This was the same for all three bolt types.
4) Bolt Type 2 displayed constant shear load at all three levels of bolt tension loads in both 20 and 40 MPa concrete mediums. The consistency of shear loads at bolts elastic yield point was more pronounced that the other bolt types.

SHEAR LOAD AND LOAD CELL READINGS

Figure 4 shows a typical shear load versus load cells readings on tensile loads applied on a bolt in bolts installed in a 40 MPa concrete medium. Point A is known as the Limit of Maximum Frictional Bonding Strength (LMFBS) which indicates shear load values whereby the load cells values began to increase from the initial applied load. This level of shear load was significantly higher than the elastic yield point shown in Figures 2 and 3 respectively. The level of shear load increase was dependent on the initial axial tensile load on the bolt, concrete type and bolt profile pattern. Figure 5 (a-f) shows the different shear load and load cell readings for various bolts. The graph profiles were different for different bolts.

The following can be observed from these figures:

- The level of initial confining axial load applied to bolts had profound influence on the applied shear load at the Limit of Maximum Frictional Bonding Strength (LMFBS) between the bolt and resin. In the majority of cases the higher was the initial tensioning load, the greater was the shear load at LMFBS. However, there was exception to this kind of loading pattern as shown in Figure 5f. The above relationship occurred irrespective of bolt type and medium strength.
- The shear load values beyond was greater than the elastic point of the bolt.
- Back sloping of the Load Cell load/ shear load graph prior to the failure of the frictional bonding strength was attributed to the crushing of the concrete blocks as indicated in Figures 5 d and f. Clearly the bolt appears to have pulled through the concrete as the shear load was increased. This phenomenon was more common in weaker strength medium such as in 20MPa concrete medium.
- Shear load vs Load Cell readings were more consistent in stronger concrete than that in weaker one. Excessive back sloping was evident in this bolt than the other bolts. Also the peak shear load at the limit of frictional bonding point was the lowest of all the bolts tested in 20 MPa concrete.
- As the holes made in the concrete blocks were not rifled, there is a reasonable chance that the relative movement between concert /resin/ bolt could have been either between the bolt and resin or between any of the two elements and at worst a combined movement involving concrete/resin and bolt.
- Bolt Type 2 installed in the 40MPa concrete have comparatively greater shear load at LMFB point than the other two bolts.
- 20 MPa concrete was to week for testing 22 mm core diameter bolts. Excessive negative sloping of the shear load and initial tensile loads of the bolts prior to reaching LMFB point values is a clear indication of the concrete block crushing at higher confining load as shown in Figure 6. In-situ such situation may arise with excessive pretensioning of bolts installed in rock stratification with weaker layers sandwiched between two relatively competent layers.

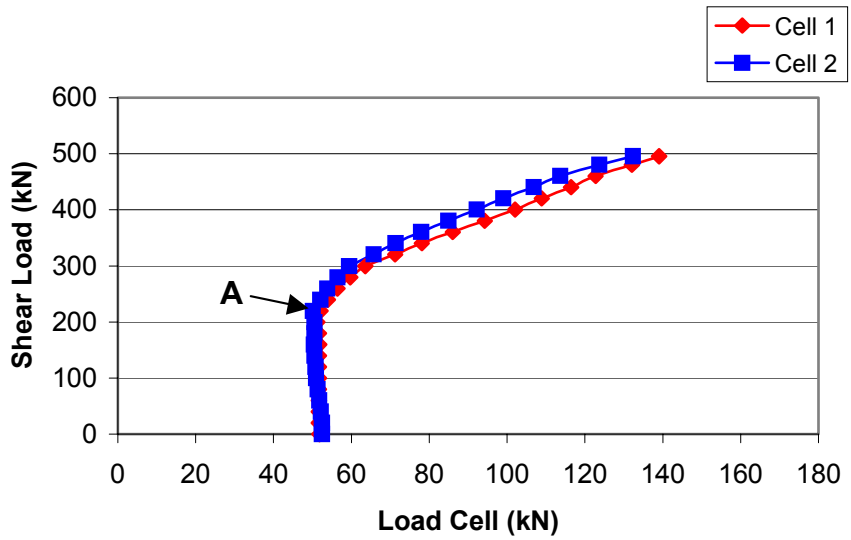

FIG. 4 - Shear load versus load cells readings on tensile load applied on a bolt installed in a 40 MPa concrete medium

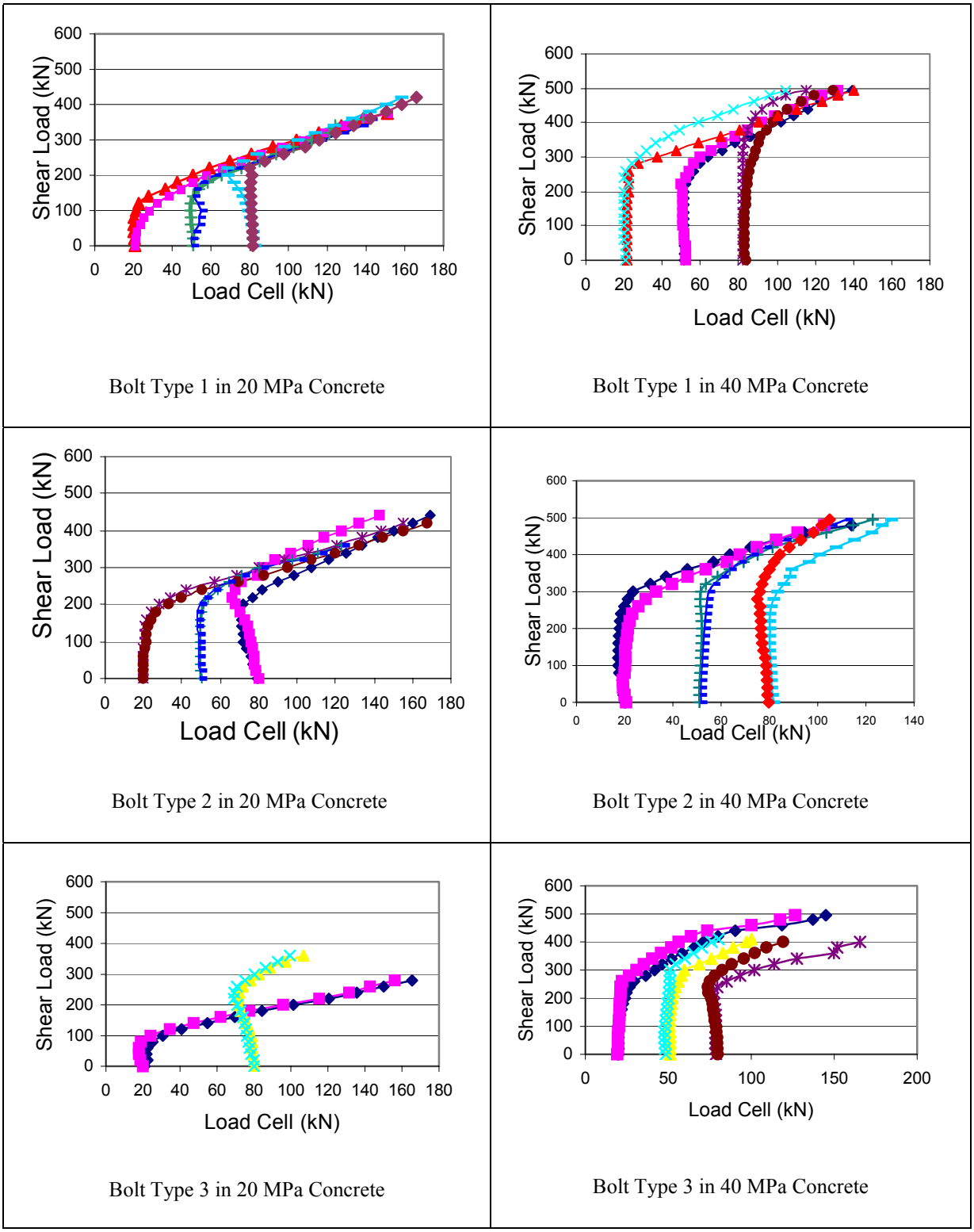

FIG. 5 - Shear load and load cell readings for various bolts with initial tensile loading of 20, 50 and 80 kN

FIG. 6 - Post test end block view of bolt pulled through the concrete during shear loading

The experimental set up for this programme of study, using 150 mm^2 side blocks was found to be relatively small and inadequate to conduct tests of such large bolt size and load application magnitudes. Plans are currently underway to conduct similar studies in mach larger blocks and in different types of rocks with rifled walled holes.

CONCLUSIONS

The double shear testing represent a useful method of assessing the bolt behaviour in multi stratified reinforcement. The technique demonstrated the role of bolt surface profiles with regard to load transfer characteristics at shear. The findings form this study were in agreement with others testes conducted with regard to the influence of bolt surface profiles on load transfer capacity of the bolts.

The technique highlighted the difficulties associated in small scale testing if concrete and testing in smooth wall holes instead of rifled holes drilled in-situ. The next phase of the study will include testing bolts in real rock samples and in much larger medium size.

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