

# The Effect of Resin Thickness on Bolt-Grout-Concrete Interaction in Shear

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## ABSTRACT

Numerical modelling is extensively used in civil and mining engineering applications because of cost and risk problems associated with different experimental studies. In this study, the effect of resin thickness was evaluated in bolt-grout-concrete interaction and bending behaviour of a fully grouted bolt installed across joints in post failure region. Tests were conducted in 20 and 40 MPa concretes, and modelling simulations were made, using ANSYS version 8.1, to include both with and without different pretension loads. It was found that in all resin thickness, both the strength of the concrete and bolt pretension had major influences on the shear resistance and shear displacement of the reinforced medium. Also it was found that the strength of the surrounding concrete is more important than that of the grout thickness in both the shear resistance and shear displacement when the bolt is pretensioned.

## INTRODUCTION

Rock bolts are one of the most popular systems of support in underground mining and tunnelling operations. Bolts can be installed as passive or as active pre-tensioned element. However, there is an ongoing debate on the methodology of bolt installation with regard to bolt pretensioning. When bolts installed in underground excavations or in surface mining, they are loaded both axially and laterally depending on the movement direction of reinforced unstable rock blocks.

Research on sheared surface reinforcement has been pursued, with increasing vigour in recent years, since the benefits of full encapsulation was realised and appreciated. A lot of alternative methods and experimental programs were performed in order to investigate the mechanical behaviour of fully grouted rock bolt in field of shearing such as: Dulacska, 1972; Bjurstrom, 1974; Azuar, 1977; Nitzsche and Hass, 1976; Hass, 1981; Hibino and Motojima, 1981; Dight, 1982; Spang and Egger, 1990; Ferrero, 1995; Pellet and Boulon, 1998; Kharchafi, Grasselli and Egger, 1998; Grasselli, 2004; Aziz, Jalalifar and Hadi, 2004 and Jalalifar, Aziz and Hadi, 2004.

The effect of resin thickness is one of most important factors to transfer the maximum load from bolt to the rock. When a bolt is loaded axially by pushing/pulling through the resin thickness, thicker resin layers show minimum load transfer. Several authors conducted this research in the past (Fabjanczyk, Hurt and Hindmarsh, 1998; Aziz and Webb, 2003; Aziz, 2004). However, to understand the effect of resin thickness while bolt is laterally loaded under shearing effect, laboratory tests and numerical simulations were conducted. Double shear laboratory tests were carried out only in 27 mm hole diameter and 22 mm bolt diameter. Afterwards an extensive numerical modelling with different resin thickness, material strength and bolt pretensioning was undertaken. This paper highlights the effective role that the resin thickness in different rock strengths and pretensions could play in rock reinforcement.

## EXPERIMENTAL STUDY

Figure 1 shows the general set up of the double shear box unit in a testing machine. Figure 2 shows the sketch of the quarter model of double shear block, the axial section of the assembled

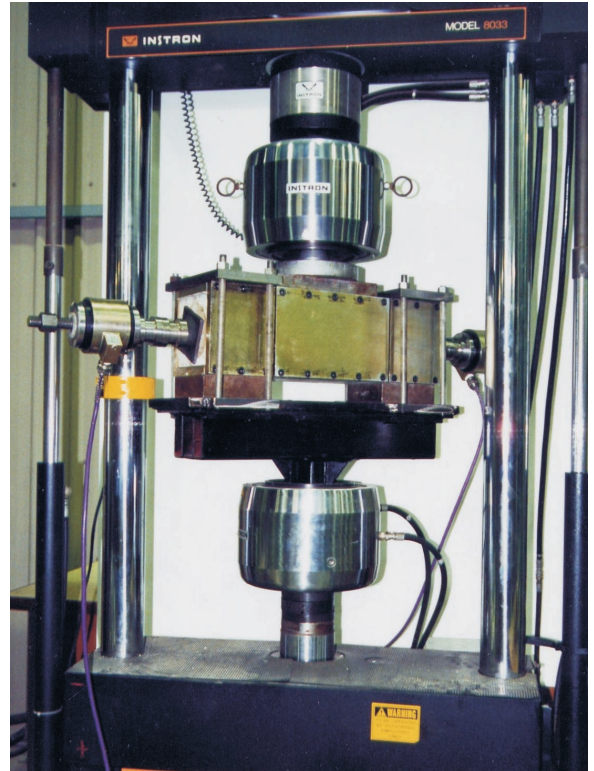


FIG 1 - General set-up of double shear box.

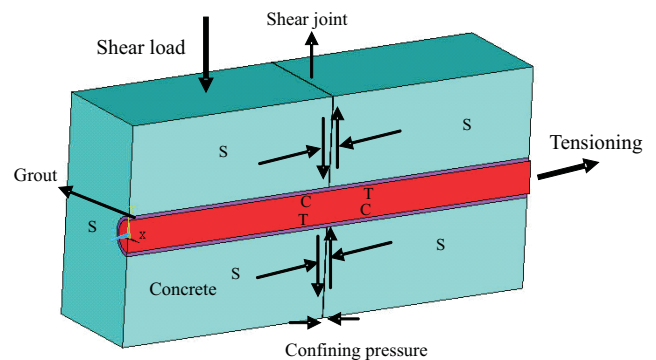


FIG 2 - Initial state of bolted joint in a quarter model. C, T, S denotes compression, tension and symmetric areas respectively.

reinforced block with various induced forces and compression and tensile zones along the bolt. Double-jointed concrete blocks were cast for each double shearing test. Two different strengths concrete blocks, at 20 MPa and 40 MPa, were cast to simulate two different strength rocks.

The concrete/bolt assembly was then mounted in a steel frame shear box specifically fabricated for this purpose. A base platform that fitted into the bottom ram of the Instron Universal Testing Machine, capacity 500 kN, was used to hold the shear

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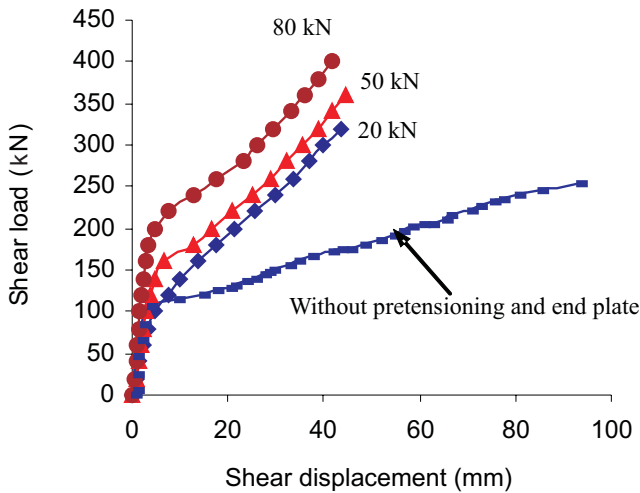


FIG 3 - Load displacement in bolt type T1, 20 MPa strength concrete and hole diameter 27 mm.

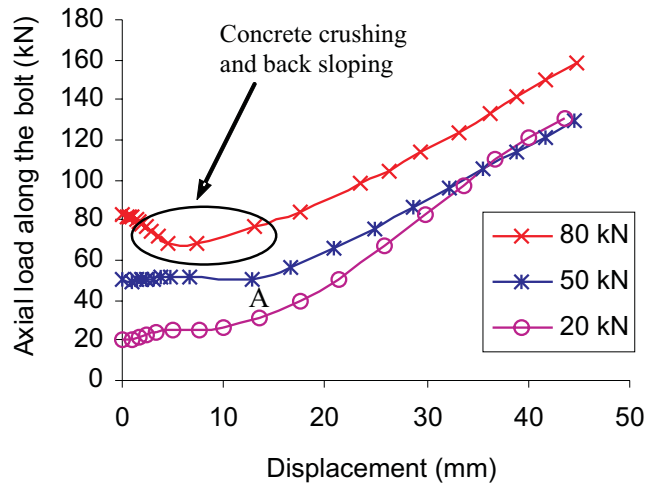


FIG 5 - Axial load developed along bolt type T1 versus shear displacement in 20 MPa concrete and different pretensioning.

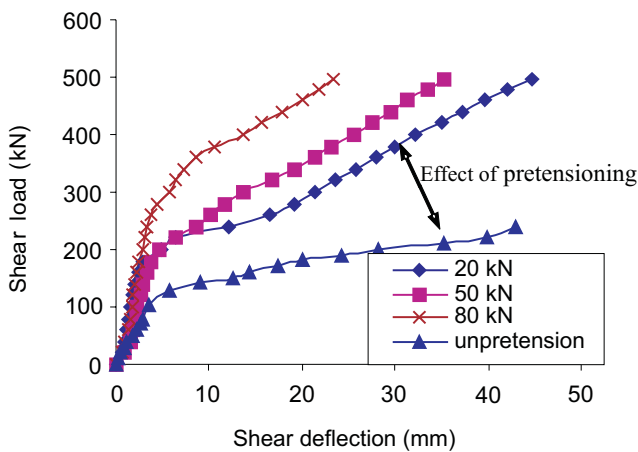


FIG 4 - Shear load versus shear deflection in bolt type T1 in different pretensioning with 40 MPa strength concrete and hole diameter 27 mm.

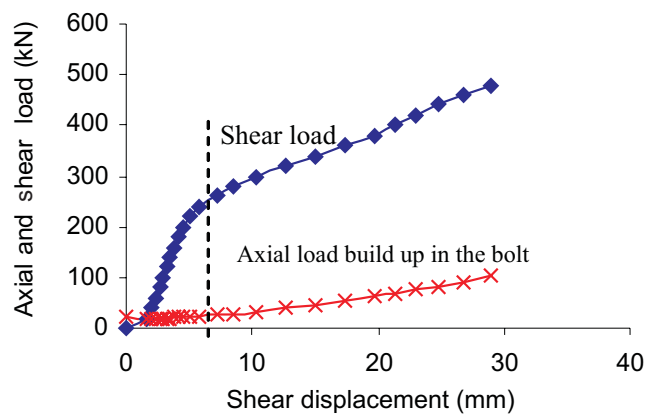


FIG 6 - Shear load and pretensioning versus shear displacement in 40 MPa with 20 kN pretension in bolt type T2.

box. 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 tension forces used were 20 kN, 50 kN and 80 kN. 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. Figure 3 and 4 show the load deflection trend for bolt type T1 in 20 and 40 MPa concretes respectively and in different pretensions installed in 27 mm hole diameter. Figure 5 shows the axial load developed along the bolt type T1 during shearing. Different graphs depict different initial pretension conditions. The axial load on the bolt increased with increasing the shear load. The rate of axial load increase is on the rise once the elastic range is exceeded. Back sloping in the graph of high initial pretension bolt load cast in weak concrete medium of 20 MPa is caused by the end crushing of the concrete leading to axial displacement and loss of pretension load. The shear load versus shear displacement of bolt type T2 in 40 MPa concrete with 20 kN pretensioning is plotted in Figure 6. It shows that the induced axial bolt load began to increase past elastic yield point. Figure 7 shows the relationship between the axial loads developed and shear displacement in bolt type T1, installed in 40 MPa concrete. From the graph it can be seen that the axially induced load on the bolt at low level of

pretensioning, is higher than that of high level of pretensioning. The possible reason is attributed to lower confinement resistance, causing the bolt to deform much more readily, with an increase in axial load of the bolt as the bolt is clamped at both ends.

### CONFIRMATION OF THE MODEL

Initially, the numerical model was calibrated by the laboratory test and after confirmation of the shear load-deflection curves, numerical simulations were carried out in 20 and 40, MPa concrete. The objectives were to examine the strains and stresses developed with different resin thickness and various pretension loads of 20, 50, and 80 kN. Twenty-four numerical models were created, to describe different resin thickness in different pretensions and rock strength. The confirmation of numerical simulations with laboratory tests is shown in Figure 8. It can be seen that the numerical simulations were found to be in close agreement with the experimental results.

### 3D NUMERICAL SIMULATION

3D FEM of the reinforced structure subjected to the shear loading was used to examine the behaviour of bolted rock joints, such as: strength of material, pretensioning and resin thickness in relation with the experimental results. Parameters considered were, the three governing materials (steel, grout, and rock) with two interfaces (bolt-grout and grout-rocks). Using ANSYS (Version 8.1), it was possible to simulate specifically the

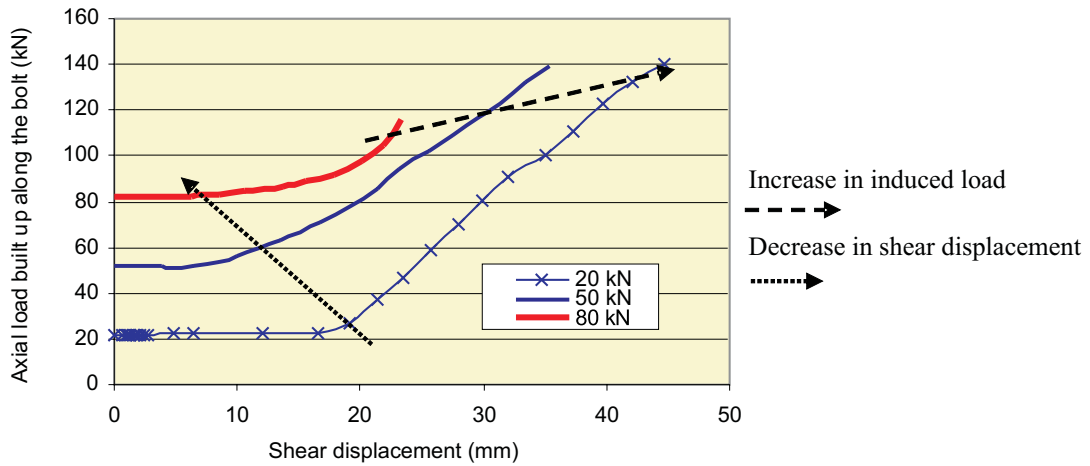


FIG 7 - Axial load build-up along the bolt as a function of shear displacement in bolt type T1 with 40 MPa concrete and with different pretensions.

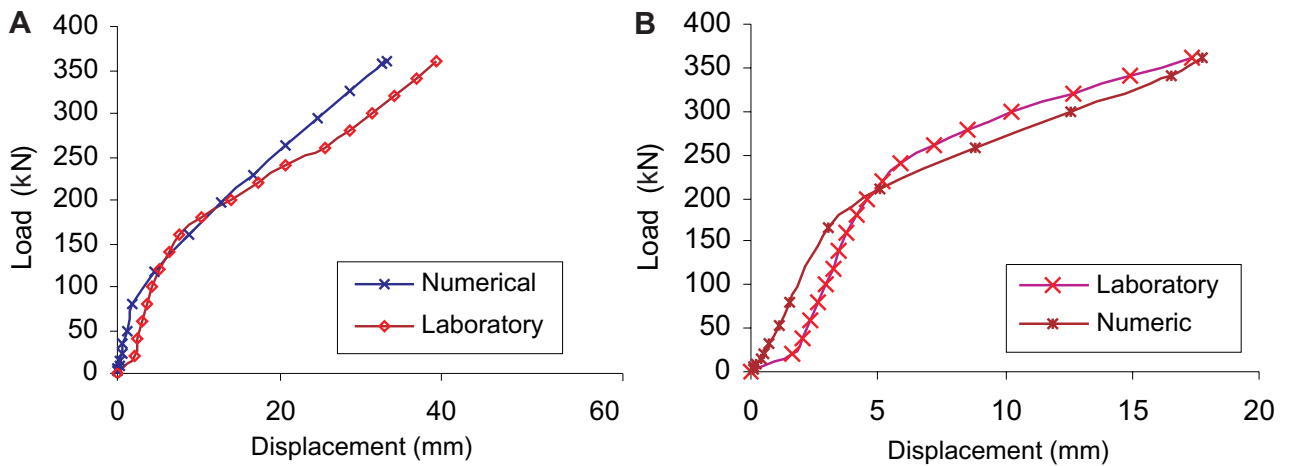


FIG 8 - Load-deflection in 20 kN pretension load in bolt type T1 with different concrete strengths. (A) 20 MPa concrete strength, (B) 40 MPa concrete strength and hole diameter 27 mm.

elasto-plastic materials and contact interfaces behaviours. The stress-strain relationship of steel was assumed as bilinear kinematics hardening model and the modulus of elasticity of strain hardening was accounted as one-hundredth of the original value. The yield strength of the steel of 600 MPa was obtained from the laboratory tests.

Numerical modelling was carried out in different thickness of resin, 1.5, 2.5 and 5 mm, in borehole diameters of 25, 27 and 32 mm respectively.

Figures 9 and 10 show the created gap among interfaces in thin and thick resin layer. From the figures it can be seen that with increasing the shear load, grout is separated from the bolt and concrete in the tension zones and is compressed at compression zone. The separation gap occurred in all resin thickness. The gap in thin resin layer is more extensive than the thick resin layer and also changes in stresses, strains and displacement along the bolt and surrounding materials. Because of extensive output results from numerical simulations, only a few figures are provided in this paper. Figure 11 shows the value of induced strain along the bolt axis around the grout 1.5 mm thick. Compared to thick resin the level of strain, in both tension and compression zones, is higher and the resin is fragmented with low shear load.

Figure 12 shows the plastic strain along the thick resin layer in 20 MPa concrete. The value of strain in the vicinity of the shear joint, through the resin, is high and causes complete damage in resin. Figure 13 displays the value of induced strain along the

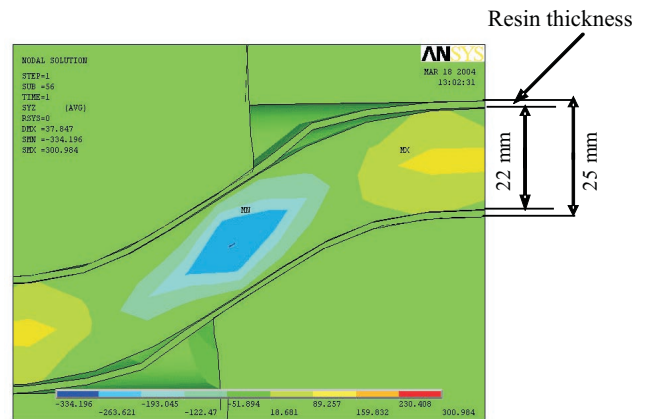


FIG 9 - Shear stress and created gap in 1.5 mm resin thickness with 20 MPa concrete without pretensioning.

bolt axis through the resin in 40 MPa concrete with 80 kN pretension. Figure 14 shows, there is a dramatic increase in strain change in the resin layer in the vicinity of shear joint. The value of strain, at both the axial and lateral directions in the vicinity of shear joint plane, was above the elastic yield point of the resin, which is a clear indication that the strength of resin is exceeded.

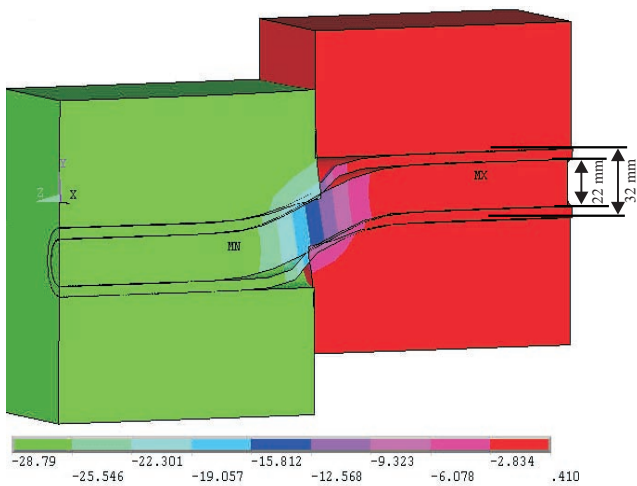


FIG 10 - Model deformation and created gap between interfaces in 5 mm resin thickness.

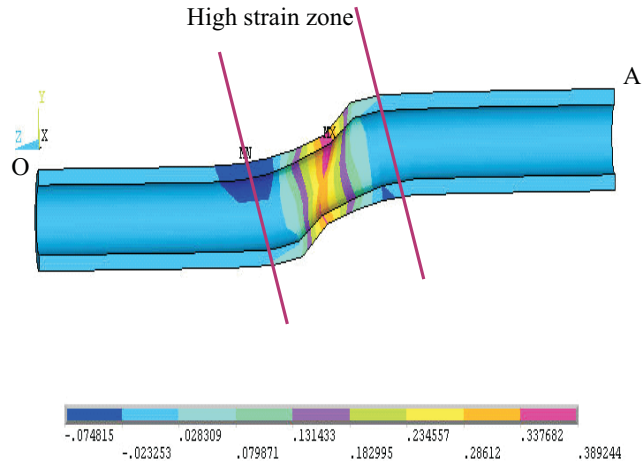


FIG 13 - Plastic axial strain along the thick resin layer in 40 MPa concrete with 80 kN pretensioning.

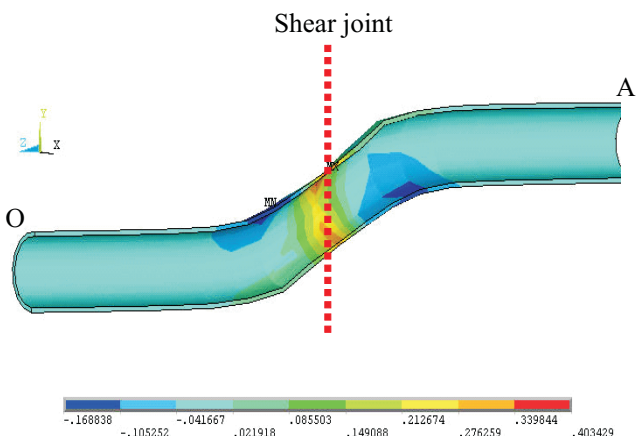


FIG 11 - Plastic axial strain along thin grout layer in 20 MPa strength without pretensioning.

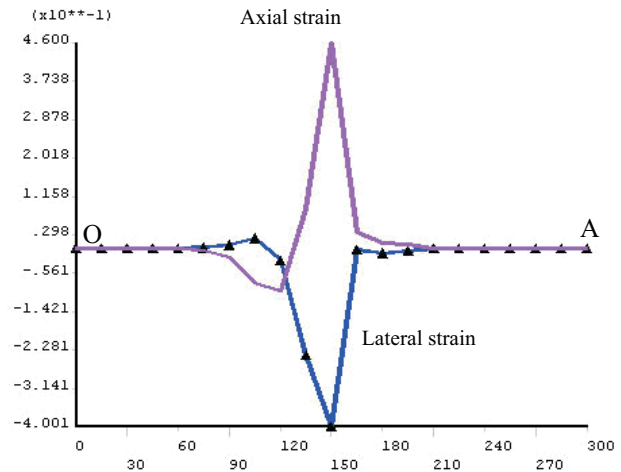


FIG 14 - Plastic strain along the thick resin layer in both directions, lateral and axial the bolt in 40 MPa without pretensioning.

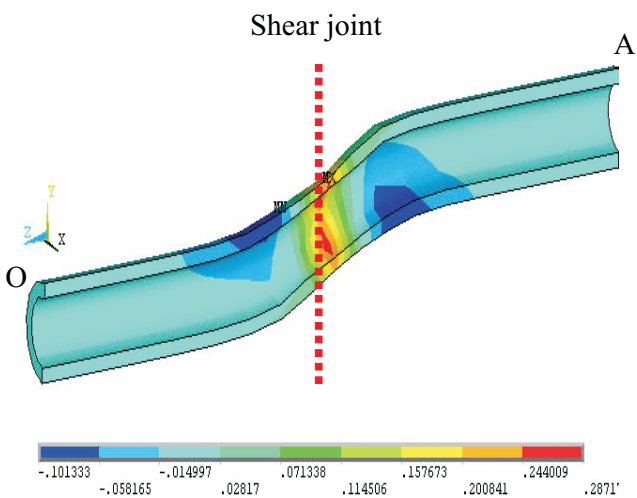


FIG 12 - Plastic axial strain along thick grout layer in 20 MPa strength without pretensioning.

Figure 15 shows the trend of induced stress and concrete deflection along the bolt axis through the concrete block. It shows that the stresses around the concrete block edges in the vicinity of shear joint are high, thus inducing longitudinal fractures in the concrete blocks (Figure 16). This was also observed at the experimental results, and was common to all resin thickness and concrete strengths. The rate of strain changes along the bolt, with thick resin thickness in 40 MPa concrete and without pretension, is shown in Figure 17. From the numerical simulation it was found that the outer layer of the bolt was yielded, however, the middle part of the bolt cross section remained in the elastic state in different concrete strength.

Figure 18 shows the yield strain contours along the bolt axis in 40 MPa concrete with 2.5 mm surrounding resin thickness and 80 kN pretensioning. From the numerical simulation it was found that with increasing bolt pretension, the area of tensile strain expanded and distributed to the middle of the bolt. Also with increasing shearing load, the surrounding material, concrete or grout applies reaction acting on the bolt length, which is progressively increased until the bolt yield. In numerical simulation, surface-to-surface contact elements of 174 and 170 were defined for contact and target interface elements respectively.



Figure 19 shows the contact pressure contours between the bolt and grout in 40 MPa concrete. When the resultant bolt bent gap is increased the contact is separated and the contact pressure is removed. At the compression zones in the vicinity of shear joint, reaction stress will result. Figure 20 shows the trend of contact pressure changes along the interface in 20 MPa concrete, which was high in the vicinity of the shear joint.

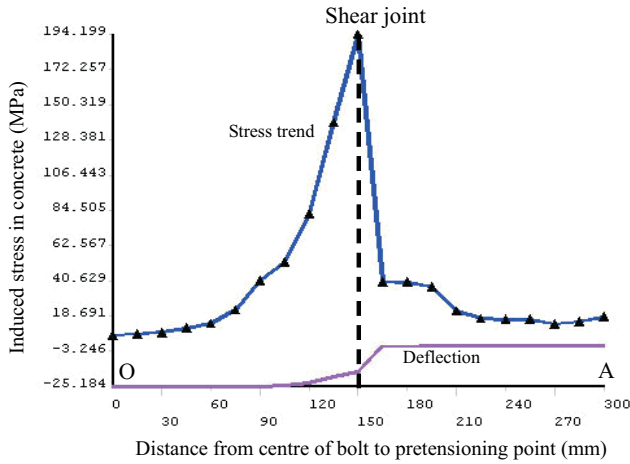


FIG 15 - Yield stress trend in concrete with 40 MPa strength and thick resin without pretension effect.

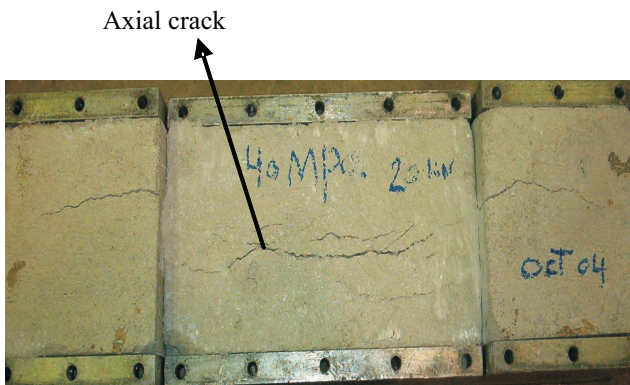


FIG 16 - Axial fracture along the 40 MPa concrete.

## THE EFFECT OF RESIN THICKNESS ON INDUCED STRESSES

The value of induced stresses in bolt was evaluated in different resin thickness. The behaviour of the concrete and grout were assumed as an isotropic linear material and the behaviour of steel bolt was assumed non-linear hardening. The effect of various concrete, grout and bolt modulus of elasticity in different resin thickness was investigated using the numerical simulations. Shear stress trend as a function of concrete modulus in different resin thickness is shown in Figure 21. The shear stress along the bolt in thick resin layer is lower than in thin resin layer. This trend was reduced with increasing concrete modulus. Figure 22 displays induced tensile stress versus grout modulus in soft concrete and in different resin thickness. The induced tensile stress along the bolt was decreased with increasing resin thickness and grout modulus.

Figure 23 shows the effect of concrete modulus on shear displacement in different resin thickness. Concrete strength has great effect on shear displacement in all resin thickness. However, not observed significant change in shear displacement in high strength concrete. The value of shear displacement in thin resin layer is higher than thick layer. As Figure 24 shows the influence of grout modulus is more effective than the concrete modulus in shear displacement for the variety of resin thickness.

## RESULTS AND CONCLUSION

This paper demonstrated that the resin thickness plays a prominent role in bolt shearing across joints and bedding planes, however its roles in shear is less significant in comparison to the conventional axial loading and load transfer characteristics. Thus, what is important and influencing the bolt shear is the strength of resin in relation to the medium strength.

The following are some of the conclusions drawn from model simulations:

1. Von Mises strain in bolt roughly was constant in 1.5 and 2.5 mm resin thickness; however, a little reduction was observed in 5 mm thickness;
2. tensile and compression strains were slightly reduced with increasing resin thickness
3. shear displacement was reduced with increasing resin thickness;

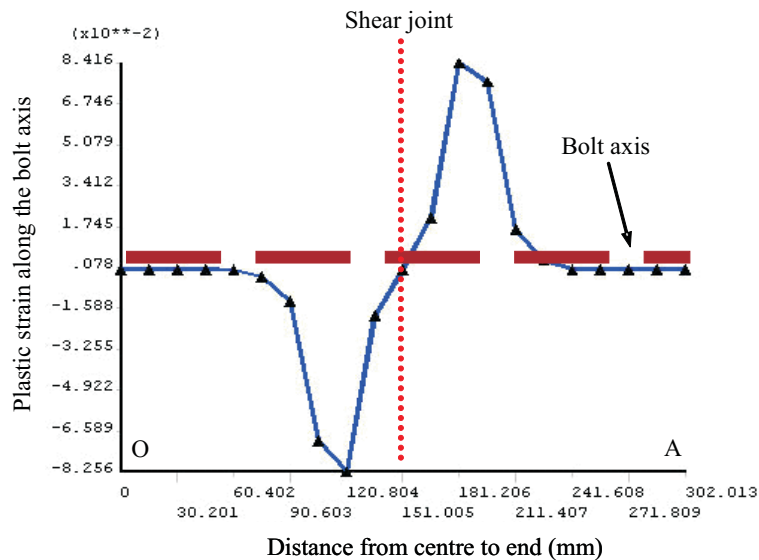


FIG 17 - Trend of axial strain along the bolt in high resin thickness (5 mm) surrounded by 40 MPa concrete.

4. with increasing resin thickness the plastic strains perpendicular to the bolt axis inside the grout were reduced;
5. compression and tensile strain along the bolt axis in concrete interface were reduced slightly with increasing resin thickness; and
6. it was also concluded that the strength of the surrounding concrete is more important than that of the grout thickness in shear resistance and shear displacement while bolt is loaded laterally.

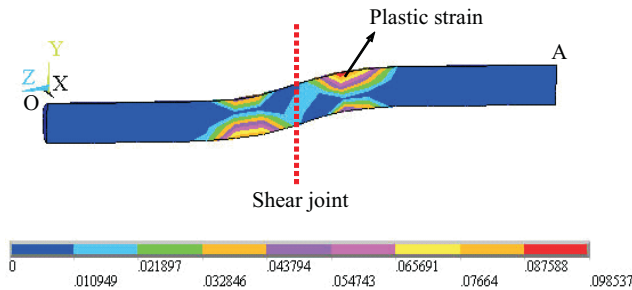


FIG 18 - Von Mises strain along the bolt surrounded by high resin thickness (5 mm) and 40 MPa concrete with 80 kN pretensioning.

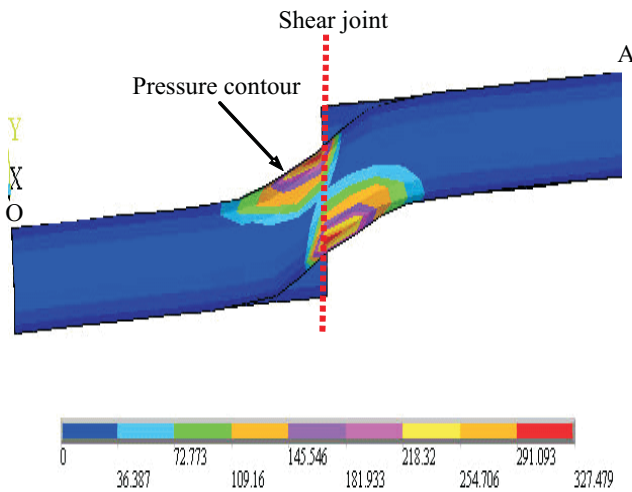


FIG 19 - Contact pressure contours in interface in with 40 MPa strength concrete.

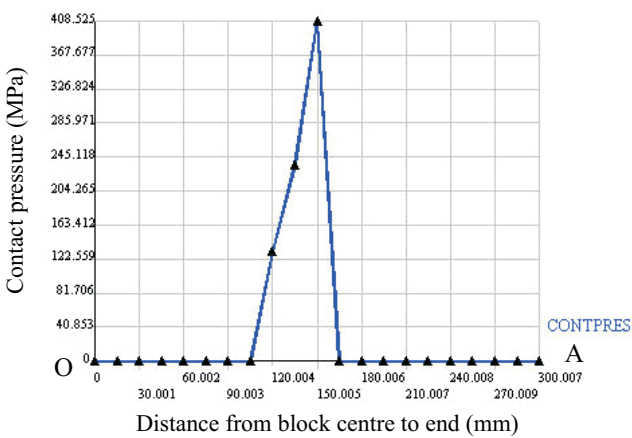


FIG 20 - Contact pressure trend between interfaces in 20 MPa strength concrete.

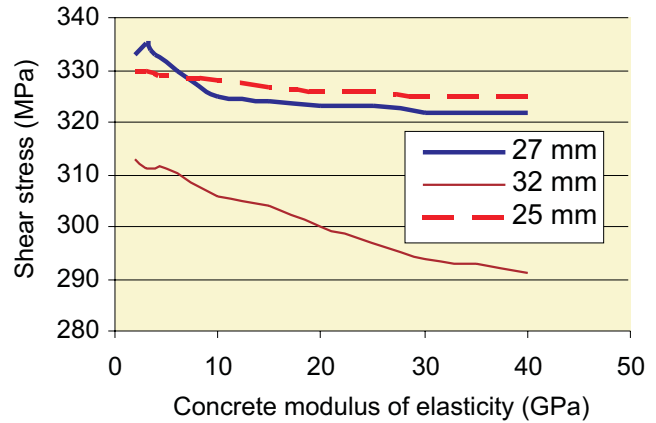


FIG 21 - Induced shear stress versus concrete modulus of elasticity in different resin thickness.

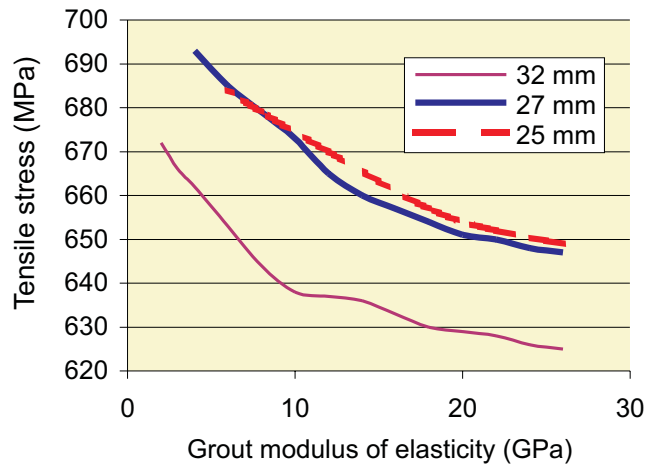


FIG 22 - Induced tensile stress versus grout modulus of elasticity in soft concrete.

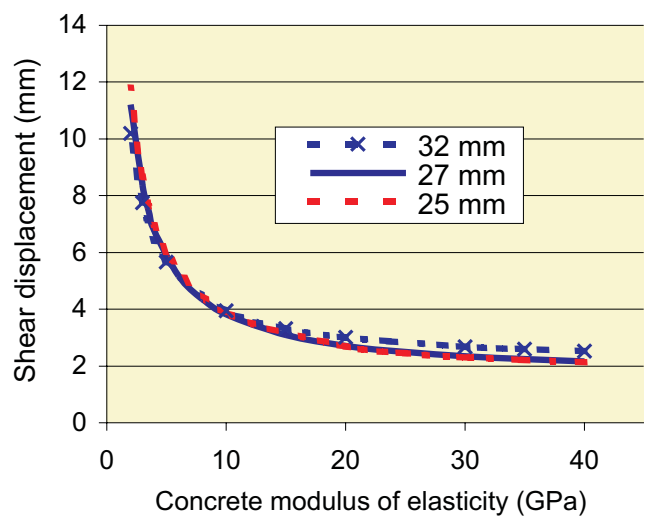


FIG 23 - Shear displacement versus concrete modulus in different resin thickness.

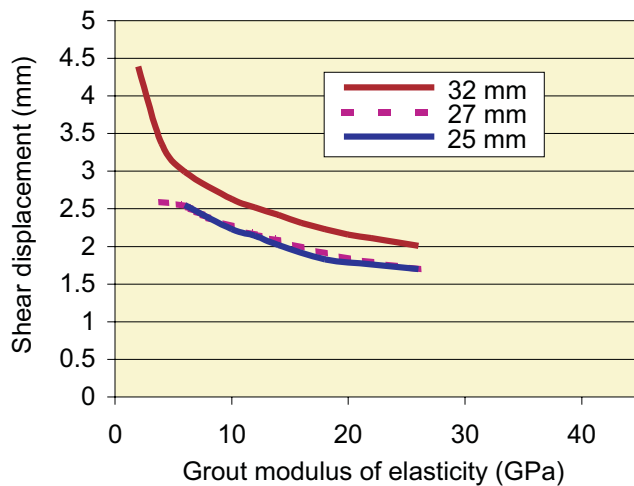


FIG 24 - Shear displacement versus grout modulus of elasticity in different resin thickness.

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