# A NEW TECHNIQUE TO DETERMINE THE LOAD TRANSFER CAPACITY OF RESIN ANCHORED BOLTS

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*ABSTRACT:* This paper describes a new technique to evaluate the load transfer capacity of different resin anchored rock bolts. With an increasing number of rock bolts currently being introduced into the Australian market for use in a variety of ground conditions, a new technique to determine bolt load transfer capacity is necessary.

The assessment of the performance bolt with regard to load transfer mechanisms is conducted in the laboratory under Constant Normal Stiffness (CNS) conditions. This method of testing is considered as being a realistic way of evaluating bolt surface roughness as the tests are carried out under different confining pressures thus accommodating the changes in ground conditions such as high horizontal stress while allowing for surface dilations due to rubbing of rough surfaces against each other.

## INTRODUCTION

In the market today there is a variety of different rock bolt designs deployed for strata reinforcement. These rock bolts vary in appearance, based on the way they are manufactured, and how they are to operate in strata support applications. This paper is only concerned with resin or grout anchored rock bolts and is not concerned with point anchored or friction anchored rock bolt system. Nevertheless, the basic resin or grout anchored rock bolt consists of a solid steel bar with some form of rib or thread profiles hot rolled onto the outside of the bar, as well as a nut and a thread at one end of the bar to enable the nut to be tightened up against the bearing plate and rock face. Irrespective of the bolt type, it is this surface profile that plays a major influence on the effective functioning of the bolt as it influences the load transfer mechanisms between rock, resin and rock bolt.

Currently there are two common methods of assessing the load transfer capability of bolts, the well-known pull out test, and short length push test. Both tests are conducted under constant normal load condition, which is applicable to shearing across planar and regular surfaces whereby the process of shearing does not produce any noticeable vertical displacement across the shearing surfaces. Thus, both systems of testing ignore the additional forces generated due to vertical displacement of the resin during the shearing process caused by bolt ribs. The results of these tests can also be influenced by such factors as the annulus thickness of the resin encapsulation and improper mixing of the resin in the hole, commonly known as gloving.

Strain gauged instrumented rock bolts installed underground is the commonly accepted method of determining the load performance of a bolt and thus the shear stress developed at bolt-resin interface (Fuller & Cox, 1975; Gale, 1986; Fabjanczyk and Tarrant, 1992 and Signer, Cox & Johnston, 1997). The shear stress developed at any point along the bolt length could then be calculated by the following formula:

$$\Delta\tau = \frac{F_1 - F_2}{\pi d l}$$

Where,
$\Delta\tau$ = Shear stress at bolt-resin interface,
$F_1$ = Axial force acting on the bolt at strain gauge position 1, calculated from strain gauge reading,
$F_2$ = Axial force acting on the bolt at strain gauge position 2, calculated from strain gauge reading,
$d$ = Bolt diameter, and
$l$ = Distance between strain gauge position 1 and strain gauge position 2.

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One of the major shortcomings of the above method is that, it does not consider the effect of horizontal stress or the confining pressure on the shear stress at the bolt/resin interface.

Accordingly, testing for load transfer mechanisms of a bolt can realistically be achieved if conducted under CNS conditions as it represents a better simulation of the changing stresses in the field. This paper describes the CNS test of bolts in the laboratory and highlights the latest modification to the future methods of testing, currently been carried out at the University of Wollongong. The findings from the laboratory study is supported with field investigation to evaluate the behaviour the two different profiled bolts under changing ground stress conditions.

## BOLT-SURFACE PREPARATION

A 100 mm length of a bolt was selected for the surface preparation for CNS shear testing. The specified length of bolt was cut and then drilled through. The hollow bolt segment was then cut along the bolt axis from one side and preheated to open up into a flat surface as shown in Fig. 1. The surface features of the bolt (ribs) were carefully protected while opening up the bolt surface. The flattened surface of the bolt was then welded on the bottom plate of the top shear box of the CNS testing machine. Table 1 shows the specification of two types of bolt used in the study, known as Type I and Type II bolts respectively.

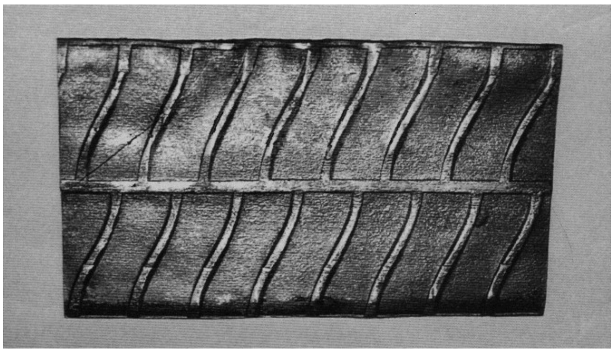


**Fig. 1. Flattened bolt surface**

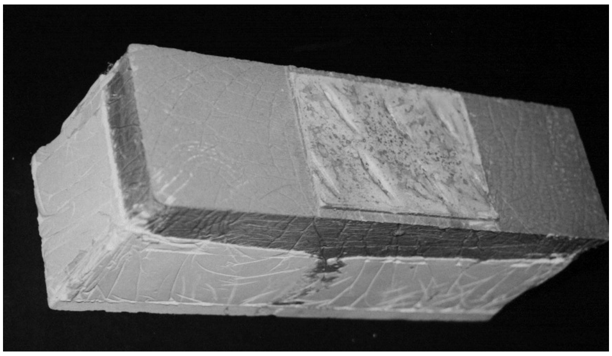


**Fig. 2. A typical cast sample**

**Table 1. Specification of bolts**

| Bolt | Core Diameter (mm) | Finished Diameter (mm) | Rib Spacing (mm) | Rib Height (mm) | Profile Width (mm) | |
|---|---|---|---|---|---|---|
| | | | | | Base | Top |
| Type I | 21.7 | 24.4 | 28.5 | 1.35 | 4.75 | 3.00 |
| Type II | 21.7 | 23.2 | 12.5 | 0.75 | 3.50 | 2.20 |

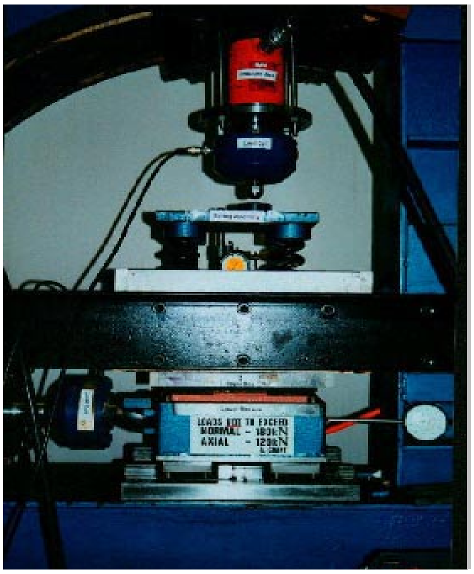
## SAMPLE CASTING

The welded bolt surface on the bottom plate of the top shear box was used to print the image of bolt surface on cast resin samples as shown in Fig. 2. For obvious economic reasons the samples were cast in two parts. The top, one-fourth layer of the sample was cast in resin and the remainder cast in high strength casting plaster. The properties of the hardened resin after two weeks were, uniaxial compressive strength ($\sigma_c$) = 76.5 MPa, tensile strength ($\sigma_t$)= 13.5 MPa, and Young's modulus (E) = 11.7 GPa. The cured plaster showed a consistent $\sigma_c$ of about 20 MPa, $\sigma_t$ of about 6 MPa, and E of 7.3 GPa.

## CNS SHEAR TESTING APPARATUS

Fig. 3 is a general view of the CNS testing apparatus used for the study. The equipment consisted of a set of two large shear boxes to hold the samples in position during testing. The size of the bottom shear box is 250x75x100 mm while the top shear box is 250x75x150 mm. A set of four springs are used to simulate the normal stiffness

($k_n$) of the surrounding rock mass. The top box can only move in the vertical direction along which the spring stiffness is constant (8.5 kN/mm). The bottom box is fixed to a rigid base through bearings, and it can move only in the shear (horizontal) direction. A hydraulic Jack is used to apply the desired initial normal stress ($\sigma_{no}$), which was measured by a calibrated load cell. The shear load is applied via a transverse hydraulic jack, which is connected to a strain-controlled unit. The applied shear load can thus be recorded via strain meter fitted to a load cell. The rate of horizontal displacement can be varied between 0.35 and 1.70 mm/min using an attached gear mechanism. The dilation and the shear displacement of the joint are recorded by two LVDT's, one mounted on top of the top shear box and the other is attached to the side of the bottom shear box. A total of 12 samples were tested for two different types of bolt surface at initial normal stress ($\sigma_{no}$) levels ranging from 0.1 to 7.5 MPa. Each sample is normally subjected to five cycles of loading in order to observe the effect of repeated loading on the bolt/resin interface. The stress profile, as described above, is defined as the variation of shear (or normal) stress with shear displacement for various cycles of loading. A constant normal stiffness of 8.5 kN/mm was applied via an assembly of four springs mounted on top of the top shear box. An appropriate strain rate of 0.5 mm/min was maintained for all shear tests. A sufficient gap (less than 10 mm) was allowed between the upper and lower boxes to enable unconstrained shearing of the bolt/resin interface.



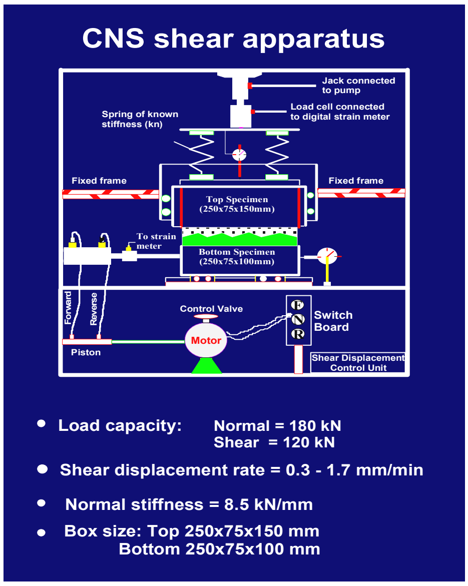



**Fig. 3. CNS apparatus**

## EFFECT OF NORMAL STRESS ON STRESS PATHS

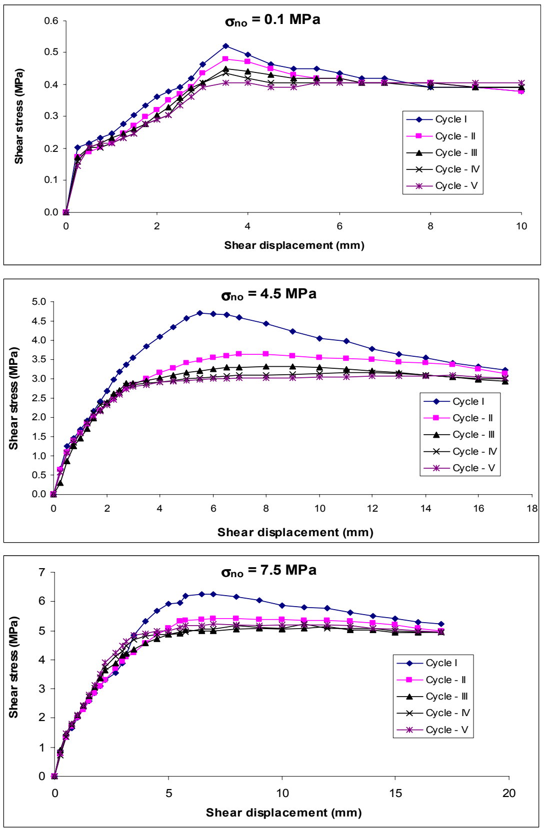



**Fig. 4. Shear Stress profiles of the Type 1 bolt from selected tests**

Fig. 4 shows the shear stress profiles of the bolt/resin interface for selected normal stress conditions for the Type I bolts. The difference between stress profiles for various loading cycles was negligible at low values of $\sigma_{no}$ (Fig. 4a). This was gradually increased with increasing value of $\sigma_{no}$ reaching a maximum between 3 and 4.5 MPa (Fig. 4b). Beyond a 4.5 MPa confining pressure, the difference between stress profiles for the loading cycles I and II decreased again (Fig. 4c). A similar trend was also observed for the Type II bolt surface (not shown in the figure). At low $\sigma_{no}$ values, the relative movement between the bolt/resin surfaces caused an insignificant shearing and slickensiding of the resin surface, thus keeping the surface roughness almost intact. For each additional cycle of loading, the shear stresses marginally decreased, especially in the peak shear stress region. However, as the value of $\sigma_{no}$ was increased, the shearing of the resin surface was also increased, and the difference in stress profiles for various cycles of loading became

## DILATION BEHAVIOUR

For the first cycle of loading, Figs. 5a and 5b show the variation of dilation with shear displacement at various normal stresses for Type I and Type II bolts, respectively. For various values of $\sigma_{no}$, the maximum dilation occurred at a shear displacement of 17 - 18 mm and 7 - 8 mm, for Type I and Type II bolts, respectively (Figs. 5a and 5b). The distance between the ribs for both bolt types is shown in Table 1. Therefore, it may be concluded that the maximum dilation occurred at a shear displacement of about 60% of the bolt rib spacing.

## EFFECT OF NORMAL STRESS ON PEAK SHEAR

Figs. 5c and 5d show the variation of shear stress with shear displacement for the first cycle of loading at various normal stresses, for both Type I and Type II bolts, respectively. The shear displacement for peak shear stresses increased with increasing value of $\sigma_{no}$ for both bolt types. This was due to the increased amount of resin surface shearing with the increasing value of $\sigma_{no}$. However, there was a gradual reduction in the difference between the peak shear stress profiles with increasing value of $\sigma_{no}$. The shear displacement required to reach the peak shear strength is a function of the applied normal stress and the surface properties of the resin, assuming that the geometry of the bolt surface remains constant for a particular type of bolt as evident from Figs. 6 and 7.

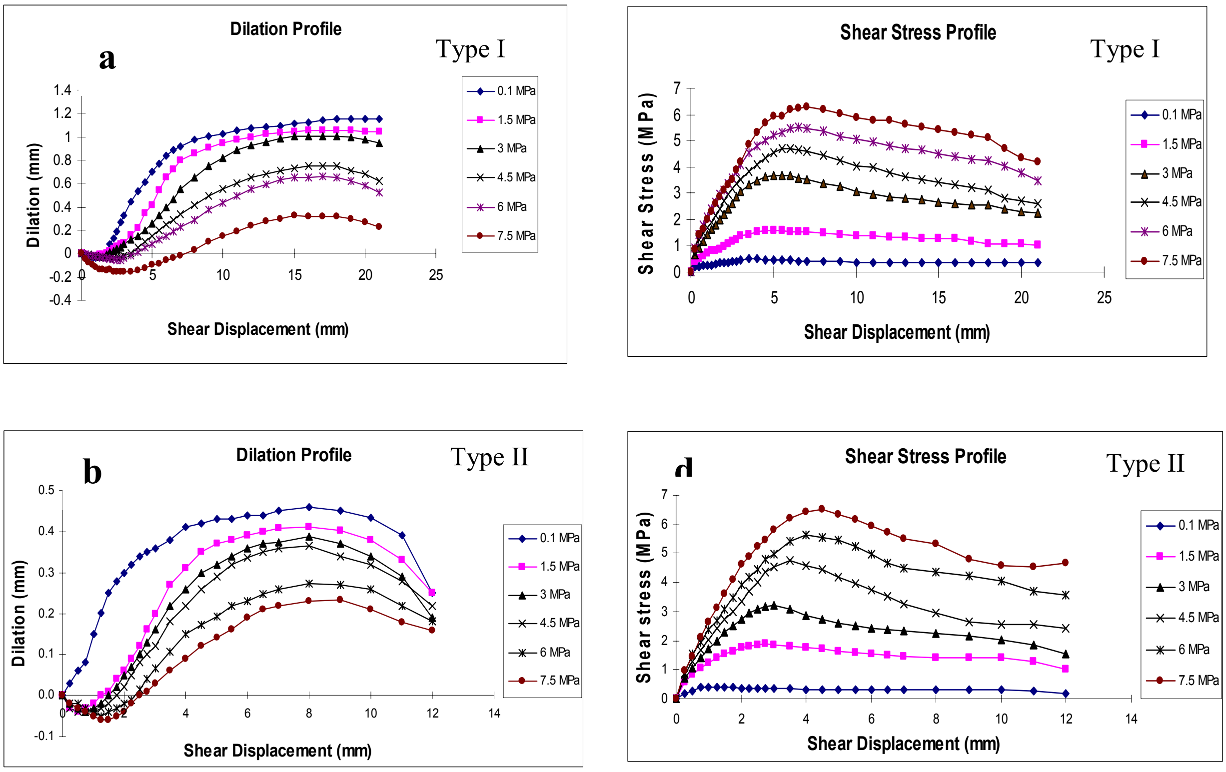



**Fig. 5. First Loading Cycle Dilation and Shear Stress profiles for both Types I and II Bolts**

## OVERALL SHEAR BEHAVIOUR OF TYPE I AND TYPE II BOLTS

Fig 6 shows the shear stress profiles of both Type I and Type II bolts for the first cycle of loading. The following observations were noted:

- The ultimate shear strength profiles for both types of bolts is very similar throughout the normal confining stress range, suggesting that it is the ultimate shear strength of the resin which is the controlling and dominant factor at play in this situation.
- Shear displacements at peak shear are higher for the bolt Type I indicating the safe allowance of more roof convergence before instability stage is reached.
- Post peak shear stress values are higher for the bolt Type I indicating better performance in the post-peak region, as closer spaced ribs would tend to break up the resin between ribs more rapidly, and therefore there will be a greater drop off in residual shear strength.
- For both bolts, the maximum vertical displacement or dilation, due to relative displacement of bolt against the resin occurred at a shear displacement of about 60% of the bolt rib spacing.

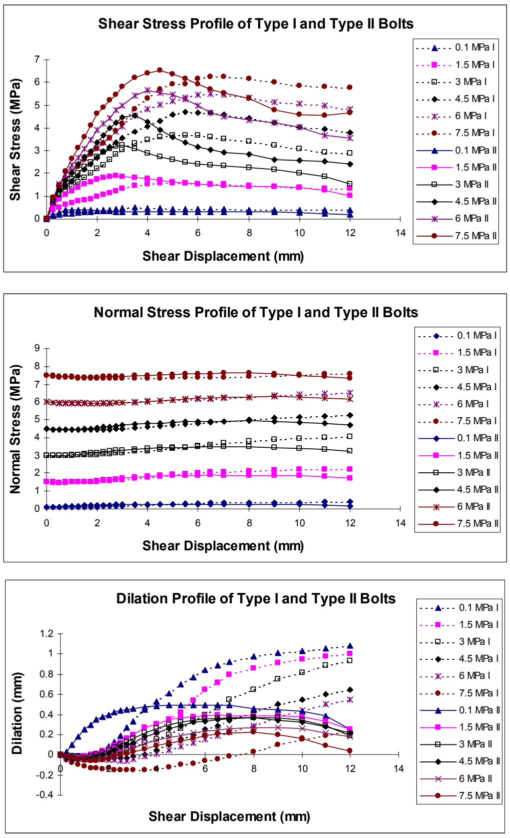



**Fig. 6. Comparison of stress profile and dilation of Type I and Type II bolts for first cycle of loading**

## EFFECT OF NORMAL STIFFNESS

The laboratory experiments were carried out with spring assembly with an effective stiffness of 8.5 kN/mm. In practice, the stiffness of resin/rock system will be usually higher than the laboratory simulated stiffness. As the stiffness increases, the effective normal stress on the bolt/resin interface at any point in time will also increase, as per the following equation:

$$\sigma_n = \sigma_{no} + \frac{k_n . \delta_v}{A}$$

where,

$\sigma_n$ = effective normal stress,
$\sigma_{no}$ = initial normal stress,
$k_n$ = system stiffness,
$\delta_v$ = vertical displacement (dilation), and
A = area of the bolt surface.

It is thus reasonable to suggest that, because of the deeper and wider spaced rib profile, the effective normal stresses values will be higher for the Type I bolt as compared to the Type II bolt as long as the confining pressure remains low and higher vertical displacement ($\delta_v$)

Fig. 7 shows the variation in peak vertical displacement (dilation) of the resin /bolt contact surfaces with the applied initial normal stress. It can be seen that at low initial normal stress condition, the stress concentration on the resin surface around the bolt ribs is not sufficient to cause resin failure. As a result, the bolt with deeper and wider spaced rib profile will offer higher shear resistance due to higher dilation. However, at high initial normal stress level where the concentrated stress around the ribs is high enough to crush the resin surface, the bolt that has lower rib spacing is least influenced by increased stress. This in indicated by a relatively flatter diminishing peak dilation curve for type II bolts as compared to type I bolts. In other words, the bolts with lower rib spacing would offer a greater resistance at high normal stress conditions. It is also worth noting that the magnitude of the vertical displacement in Type I bolt is gradually tapering off as the initial normal stress increases.

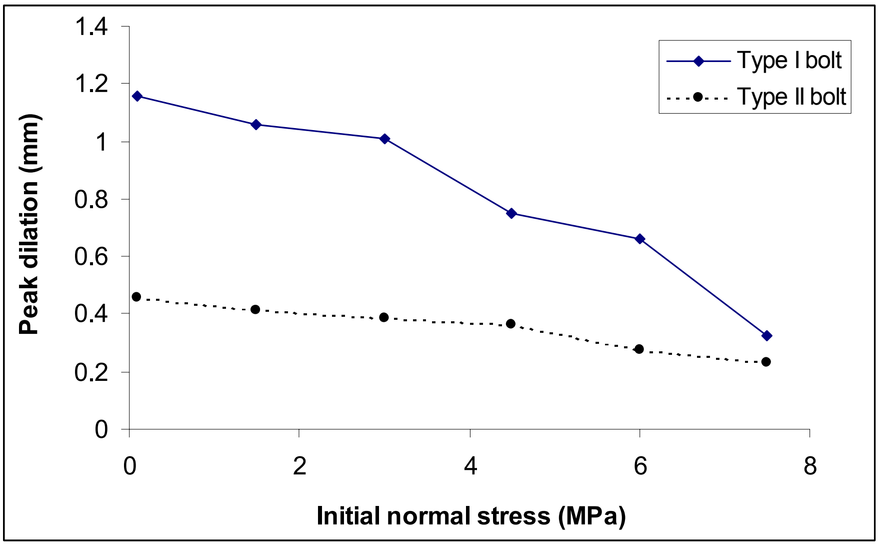



**Fig. 7 Variation of peak dilation with initial normal stress.**

## FIELD INVESTIGATION

As a part of the research project, field investigations were carried out in a local mine. Six, 2.1 m long, strain gauged instrumented bolts (three bolts from each type) were installed in the roof at a longwall panel cutthrough . The spacing between the strain gauges mounted on each bolt was 200 mm. As can be seen from Fig. 8 the pattern of roadway bolting consisted of six bolts in a row and the spacing between the rows was 1 m. The primary horizontal stress around the region was estimated at around 16 MPa. Excessive guttering at the left side of the cut through manifested the impact of high horizontal stress. Thus, the bolts on the left side of the cut through are likely to be subjected to excessive shear loading as compared to the right side bolts of the cutthrough.

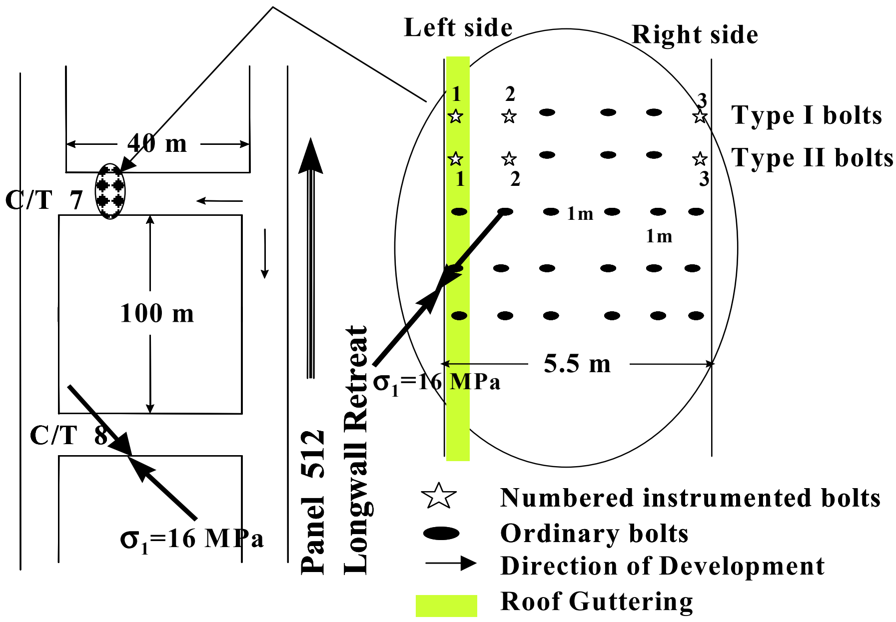



**Fig. 8 Plan of instrumented site**

Fig. 9 shows the magnitude of load generated on Type II bolts across the cutthrough, and shows that the bolt on the left side of the cut through experienced relatively higher load transfer in comparison to the bolt at the right side. However, the level of load generated on Type I was different from that of bolt Type II. The variations in the calculated shear stresses for different bolts are shown in Fig. 10. No load build up comparison was possible for the bolts installed in the middle of the cut through as the mid section Type I bolt malfunctioned after a short period of installation. Fig. 11 shows the maximum recorded load and shear stresses generated for both types of bolts during six months of field monitoring of the site.

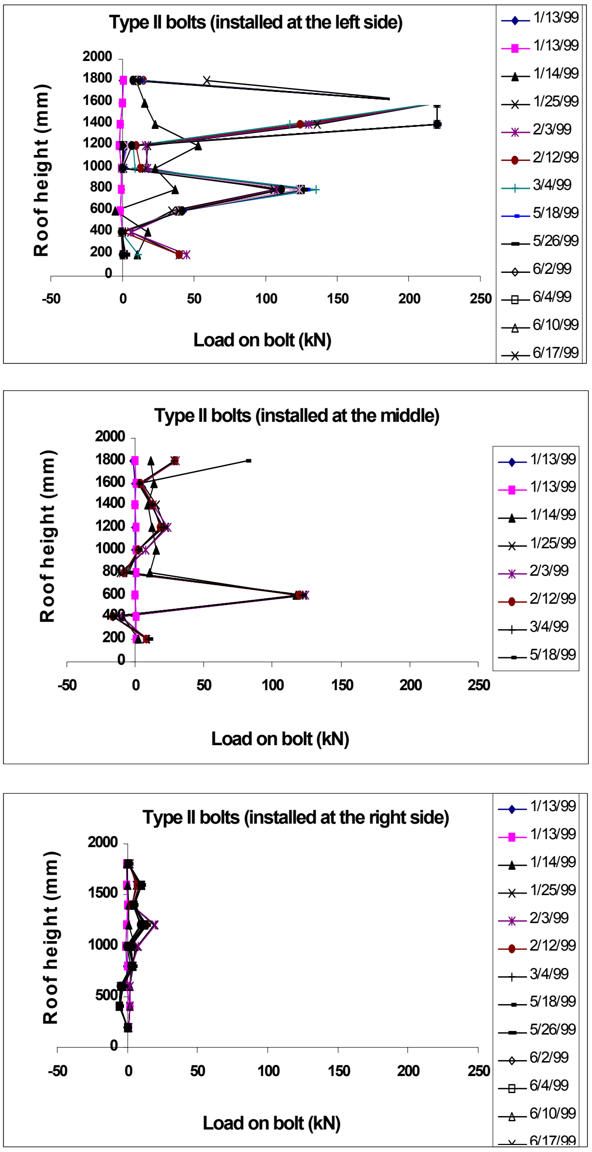



**Fig. 9. Comparison between Type I and Type II bolts**

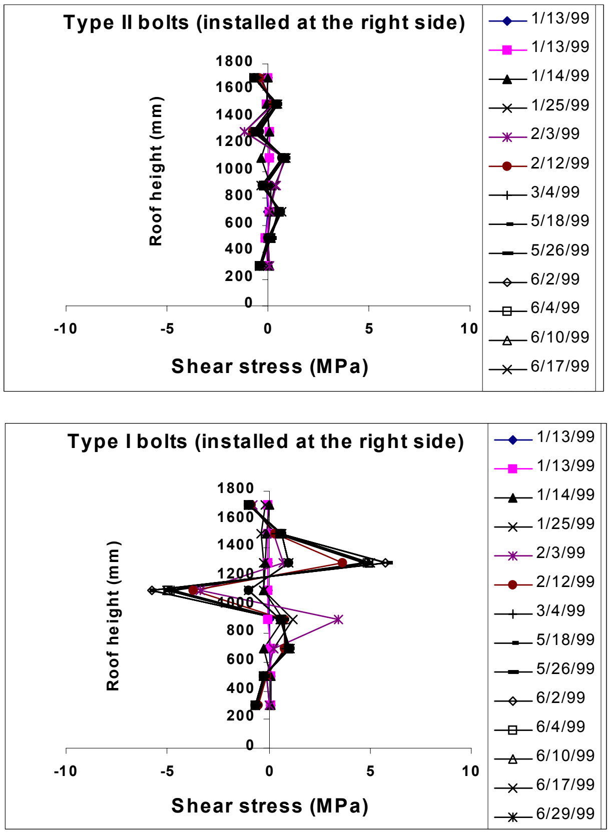



**Fig. 10 Shear stress patterns genetrated on both Type I and Type II bolts at the right side of the cut through**

The following points can be drawn from the field study:

1) Relatively higher shear stress was generated on Type II bolts on the highly stressed guttered side of the cut through in comparison to Type I bolt.
2) Relatively higher load was generated on the Type I bolts on the low stressed and gutter free right side of the cutthrough in comparison to Type II bolts.
3) Both the above findings are in agreement with the laboratory findings and above stated empirical relationship related to effective normal stress ($\sigma_n$).

4) The instrumented bolts provide a suitable technique in conducting comparative tests in the field to evaluate the suitability of any particular bolt for the prevailing ground conditions.

| Bolt Type I | L | R |
|---|---|---|
| **Axial Load (kN)** | **87** | **66** |
| **Shear Stress (MPa)** | **6.3** | **5.8** |
| **Bolt Type II** | **L** | **R** |
| **Axial Load (kN)** | **220** | **19. 5** |
| **Shear Stress (MPa)** | **16** | **1. 2** |

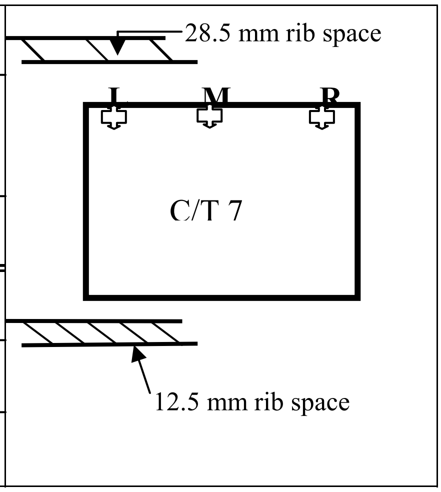



**Fig. 11. Maximum recorded load and sheer stresses**

## CONCLUSIONS

The paper described a new approach to evaluating the load transfer mechanisms in bolts with respect to variations to changes to surface profile of the bolt. The CNS method demonstrated that the technique is a viable alternative to conventional tests for evaluating effectively the load transfer capacity of different rock bolts. The laboratory findings were supported by the variations of the level of load build up on the bolts with respect to the type of the bolt. The benefit of this suggested technique can only be fully appreciated by conducting comparative studies in the field.

Research is currently being undertaken on two more new techniques, which will provide a much faster methodology of evaluating the load transfer mechanism of bolts in the laboratory. These include testing of intact bolts under biaxial conditions and double shear test. The development and refinement of these testing procedures will enable a better understanding of rock bolt behaviour and thus enable engineers to design more effective strata support products.

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