A new approach in determining the load transfer mechanism in fully grouted bolts

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CHAPTER ONE

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1.1. GENERAL

The stability and improvement of underground excavations and surface slopes is of major concern to geotechnical engineers and facility operators because failures may have severe consequences. The mechanisms, factors, and conditions associated with instability must be clearly understood so that stabilisation and reinforcement of the structure can be undertaken. Rock reinforcement is a specific technique within the general category of improvement methods which includes every technique designed to increase the strength or decrease the deformability of a rock mass. Stabilising a rock mass by bolting has been used all over the world for more than a century (Snyder 1983). In civil and mining engineering projects various kinds of rock bolts, either mechanical, grouted, or anchored, are considered to be one of the principal support members.

Various types of rock bolting methods have been used since the nineteenth century, indeed bolts were used in a coal mine in 1918 in Germany (Lang et al 1979); a wooden bolt was used to prevent small pieces of rock falling between the face and the main support system. Palmer and et al (1976) concluded that limiting displacement was the key parameter of the bolting action.

Because the behaviour of rock mass and rock bolt, including their complicated interaction, was not understood, rock bolts were not developed and used as they are
today. In recent years rock bolt systems are used in mining and civil structures and have become a dominant measure in mining engineering for supporting rock. This is because of advances made in understanding bolt failure and improvements in strata control technology. To minimise roof failures, fully grouted rather than mechanically anchored bolts are increasingly being used in mines because fully grouted bolts have a greater area of anchorage. The majority of more than 100 million roof bolts installed each year in the United States are fully grouted resin bolts (Maleki 1992). Bolts reinforce rock walls around underground excavations and are very effective in closely jointed rocks and soft rocks. A rock reinforcement system increases the safety factor against crack initiation and influences the orientation of existing cracks. A resin reinforcement system transfers the load from unstable rock layers through itself to stable rock. The reinforcement system and load transfer concepts have been used to define three fundamental types of reinforcement systems (Windsor and Thomson 1993):

- Continuous mechanically coupled (CMC) systems,
- Continuous frictionally coupled (CFC) systems and
- Discreetly mechanical or frictionally coupled (DMFC) system.

The load transfer between rock bolt and borehole depends on borehole diameter, annulus thickness, bolt profile, and so on. And in a fully grouted rock bolt, the load transfer mechanism depends on the shear stress attained on the interfaces between bolt - resin and resin - rock. The shear stress of the interfaces and rate of shear stress generated determine how the bolts respond to the strata. Research on rock bolts gained momentum following the introduction of new Austrian tunnelling method (NATM) in the early sixties, and since its introduction more than 30 years ago, resin
grouting has significantly improved roof bolting, a process that is still continuing. Many researchers have worked theoretically and experimentally on the application of fully grouted rock bolts but very little research has been carried out on the mechanism of load transfer. Littlejohn and Bruce (1975) conducted the first systematic study on the failure of a rock bolt system and suggested three modes of failure:

- Failure of rock mass,
- Failure of rock bolt and
- Failure of bolt at the grout - rock interface.


and Mahony et al (2005). All the experimental testing of grouted bolts was performed as a single shear test without tensile loads on the bolt, but in some instances a confining pressure was applied to the moving block.

To the best of author’s knowledge no suitable literature was available at the time of writing to report on any effect of bolt profile configuration in bolts installed perpendicularly at the joints and also the effect of pre-tension loads in this situation.

1.2. KEY OBJECTIVE

1. Evaluating the shear mechanism in bolt - grout and grout - rock interfaces in both laboratory and field,

2. To design and develop a shear testing machine which removes non-equilibrium problems in previous machines,

3. Study the capacity to transfer load in bolt - grout - rock interfaces, in both field and laboratory, using different types of bolts,

4. The effect that the thickness of resin has on the shear behaviour of bolts subjected to axial and lateral loading,

5. The effect of rock strength on the bending of a bolt,

6. The effect that pre-tension load has on a bolt under shear and on the load transfer mechanism.

7. The effect of bolt profile configuration, rib height and rib spacing, on load transfer under various level of pretension load and different strength surrounding materials.

8. To better understand the exact nature and quantitative significance of the load transfer mechanism with respect to the resistance of bolts to shear.
9- Numerical simulation of the interaction between bolt, joint, and concrete under axial and lateral loads.

1.3. METHODOLOGY

Laboratory tests and numerical modelling constitute the main components of this research work. A DSS (Double shearing system) was used in the laboratory to test bolts subjected to shearing and bending. Push and pull tests were used to define a load transfer mechanism subjected to axial loading, and the 3D finite element program ANSYS was used to determine the stress, strain, and interaction between bolt, grout and concrete, bolt and grout, and grout to concrete interfaces.

1.4. SCOPE

This thesis consists of 10 chapters with a flow chart of their arrangement shown in Figure 1.1.
Figure 1.1. Structure of Chapters
CHAPTER 1: Introduction

- Chapter 1 presents the general purpose, methodology, and key objectives.
- Chapter 2 describes the rock bolt system, application, and reinforcement mechanisms, including the advantages of fully grouted rock bolts. It also includes the theories of bolts, their types, and descriptions and gives a brief review of their behaviour and load transfer mechanism subjected to axial loading. Experimental and analytical approaches are also discussed.
- Chapter 3 reviews bolts bending under lateral loading, both theoretically and experimentally. It evaluates the mechanical and physical properties of the various materials used in the study including the bolt, grout, and concrete.
- Chapter 4 describes the load transfer mechanism of a bolt under axial load. Different types of bolts with different profiles were examined under a push and pull test.
- Chapter 5 examines a bolt sheared across the joint. It describes the experimental procedure and use of the double shearing system. Six different types of bolts were tested in different strength concrete under various pre-tension loads, 0, 5, 10, 20, 50 and 80 kN respectively.
- Chapter 6 describes the effect of the thickness of resin on bolts shearing. For this reason tests were conducted on the same type of bolt, pre-tension load, and concrete strength.
- Chapter 7 reviews the application of finite element to a rock bolt. 32 models were created to define the effect of concrete strength, resin thickness, and different pre-tension loads on the load built up along the bolt, grout, and concrete during shearing. The stress and strain developed along a bolt subjected to axial load is discussed.
• Chapter 8 reviews the analytical methods used to study bolts bending and predict the location of the hinge point under elastic and plastic conditions. A numerical evaluation of the distribution of axial load along an elastic bolt installed in an elasto - plastic rock mass in a circular tunnel.

• Chapter 9 describes the field work study to examine the influence of bolt surface profile on the load built up along the bolt. This study was carried out at two mines in the Southern Coalfields of NSW. Strain gauged instrumented bolts were used.

• Chapter 10 summarises the results and principal conclusions of the work presented in this thesis and offers recommendations for further research.