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

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NOTE

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CHAPTER 9

FIELD INVESTIGATIONS

9.1. INTRODUCTION

To verify the experimental findings with respect to the influence of bolt profile on load transfer, a programme of field studies was undertaken in two local coal mines in the Southern Coalfields of the Sydney Basin, in NSW, Australia. At each site two types of bolts with different profiles were installed across each roadway serving a retreating long wall face to compare their load transfer capabilities. This study was carried out by strain gauge instrumentation on each bolt. At the Metropolitan site the instrumented bolts were installed on the travelling road 255 m in front of the retreating long wall face.

At Appin they were installed on the belt road, 700 m away from the retreating long wall face. The methodology of their installation, positioning, and regular monitoring is the subject of discussion in this chapter.

9.2. SITE DESCRIPTION

9.2.1. Metropolitan Colliery

Metropolitan Colliery is an underground coal mine situated in the Southern Coalfields of the Sydney Basin in NSW, Australia, some 35 km North of Wollongong (Figure 9.1). The mine utilised a long wall operation and continuous
miner for heading development and long wall gateroads. Average thickness of the Bulli seam in the instrumented site was around 3 m. Underground access is by drift and shaft. A representation of the geological section and related strength of materials close to the experimental site is illustrated in Figure 9.2. The roof is mainly sandstone and mudstones, and is classified as moderate to strong. A detailed layout of the mine and location of the long wall panel is shown in Figure 9.3. Maximum horizontal stress at Metropolitan Colliery is based on measurements in G panel, Tarrant (2002) was between parallel to the gateroads (030/150 relative to GN) to 30° West of the gateroads (060/120 relative to GN).

Figure 9.1. Geographical location of (a) Metropolitan and (b) Appin Colliery

Metropolitan Colliery currently drives gate roads N-S and extracts long wall S-N. From the stress measurements it was found that the horizontal stress $\sigma_1 = 25$ MPa, oriented between parallel with the current heading direction and 30° west of the
heading direction. $\sigma_2 = 15$ MPa to 17 MPa and $\sigma_3 = 12.5$ MPa vertical. It should be noted that these measurements were conducted in sandstone with Young’s modulus of 16 GPa.

Six, 2.1 m long instrumented bolts were installed at the site. Three bolts were Bolt Type T1 and three were Bolt Type T3. The bolts were installed in the long wall panel between C/T 7 and 8. Figure 9.4 shows this installation. Figure 9.5 shows the installation pattern of bolts in a row placed 1 metre apart. Three extensometer probes were installed between the two rows of bolts but no extensometer monitoring occurred because the readout box malfunctioned.

Figure 9.2. Modelled geological section and strength profiles (SCT report 2002)
Figure 9.3. Detailed layout of the panel under investigation indicating instrumentation site at Metropolitan Colliery

Figure 9.4. Photograph of the site with installed bolts in Metropolitan Colliery
9.2.2. Appin Colliery

Appin Colliery is located in the coalfields of the Sydney Basin in NSW, Australia. It is approximately 40 km NW of Wollongong (Figure 9.1b). The long wall extracts coal from the Bulli seam. The seam is approximately 2.7 m thick. The retreat long wall operates with a 250 m wide face and 3 km long panel at a depth of around 480 m. The mine produces about 3.2 m tonnes of coal annually. Access to the workings is by two drifts and a shaft with the latter being used for ventilation and gas drainage. The instrumented site at Appin was in the main gate road of long wall panel 408. The selected site was 30 m from a 5m wide dyke, which traversed the long wall panel. Maximum horizontal stress at Appin Colliery based on measurements was near parallel to the gate roads. The initial horizontal stress ($\sigma_h$) around the region was estimated at 25 MPa, as shown in Figure 9.6.
Instrumentation arrangement at Appin Long wall gate road site was similar to the Metropolitan Colliery. The site consisted of three 2.1 m long Bolt Type T1 and T3 installed in the pattern shown in Figure 9.7.

All these bolts were located to the right side of the roadway because the long wall gate conveyor made it difficult to install the bolts vertically and parallel to each other. No extensometers were installed because the readout unit malfunctioned.

Two bolts failed to function, post installation, and could not be salvaged after repeated attempts to rectify them. The site was later reinforced with secondary supports in the form of 8 m long mega bolts, which obviously affected the level of the load build up on the adjacent bolts (Bolt Type T3). Figure 9.8 shows the site with bolts installed in Appin Colliery.
Figure 9.7. Detailed layout of the panel under investigation indicating instrumentation site at Appin Colliery (M = main gate, T = bolt type)
9.3. INSTRUMENTATION

The instrumentation consisted of six instrumented bolts and three extensometers, which malfunctioned and were not repaired until after the termination of data gathering due to the retreating Long wall faces overrunning both sites.

9.3.1. Instrumented bolts

Figure 9.9 shows the section of a bolt with engraved channels. There were nine stain gauges mounted on each channel 200 mm apart. The slots were filled with silicon gel to cover up the strain gauges. Figure 9.10 shows a typical strain gauged instrumented bolt used for monitoring the development of load in roof stratification with respect to the approaching long wall face. 18 strain gauges were installed in two diametrically opposite side channels, 6 mm wide and 3 mm deep, cut axially along the bolt length. 

Figure 9.8. Photograph of the site with installed bolts in Appin Colliery
a section of an instrumented bolt with strain gauges and wirings visible through the silicon cover.

Figure 9.9. Bolt segment showing channels

Cross Section
Slot: 6 mm x 2.5 mm
Slot Area: < 10%

All Strain Gauges are 5 mm, 120 Ω, Gauge Factor 2.15

Figure 9.10. Strain gauge and bolt layout
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Figure 9.11. A section of an instrumented bolt showing the strain gauge and wirings through the silicon gel

9.3.2. Intrinsically safe strain bridge monitor

An intrinsically safe Strain Bridge Monitor (SBM), IS2000, was used for the underground measurement of strains developed in the instrumented bolts. The following description of the SBM is based on an operation handbook prepared by Strata Control Technology Operations Pty Ltd. The SBM is an electronic instrument (readout box) that is used for:

- Stress monitoring
- Measuring bolt loads
- Measuring shear displacements
- Other strain gauge monitoring applications

The SBM is fully approved for use in Australian Coal Mines. The instrument is portable and battery powered requiring recharging periodically. When used underground, the SBM is connected to the instrumented bolts by electric leads. Measures were taken throughout the experiment to protect the SBM, leads, and connections, from ingress of moisture and dust as these could seriously affect the results. The SBM is set to operate with the more commonly used 120Ω strain gauges. With an appropriate bridge circuit it was possible to measure the strain in a single
gauge, two gauges, or four gauges. The quarter bridge configuration used in this experiment was restricted to 120Ω strain gauges only. As the SBM had a fixed gauge factor setting of 2.00, the actual strain indicated by the display could be calculated as follows. A general view of the SBM while taking a reading underground is shown in Figure 9.12.

\[
E_g = \frac{2V_d}{G} \quad \text{For quarter bridge configuration} \tag{9.1}
\]

\[
E_g = \frac{V_d}{G} \quad \text{For half bridge configuration} \tag{9.2}
\]

\[
E_g = \frac{V_d}{2G} \quad \text{For full bridge configuration} \tag{9.3}
\]

where;

\(E_g\) = The mean actual strain measured by an active gauge,

\(V_d\) = The change in SBM reading, and

\(G\) = The gauge factor of the strain gauge.

Figure 9.12. A general view of the SBM, while taking readings in underground
9.4. FIELD MONITORING AND DATA PROCESSING

9.4.1. Metropolitan Colliery

Figures 9.13 and 9.14 show the load developed on Bolt Types T1 and T3 with respect to the retreating long wall face positions. The graph shows load development at each of the right, middle, and left bolts. Additional data and results are presented in Appendix E.

Because the site was located in the service roadway it was possible to monitor it from the initial long wall position 255 m ahead of the site to when the long wall face passed the site by 260 m. The load development on the bolts varied depending on their location and distance away from the line of mega bolt secondary support systems installed on the right hand side of the roadway. As can be seen in Figure 9.13, Bolt Type TRT1-3, which is further away from the mega bolt line, had several strain gauges malfunction and the readings could only be obtained from the lower strain gauges up to 1.2 m in the hole. Maximum load was generated on Bolt Type T1 1600 mm above the collar and nearly at the end.

Despite the mega bolt installation on the right side of the road, higher shear loads were developed along Bolt Type TRT3-1, which was close to the mega bolted. This load was developed some 1600 mm above the collar. This was greater than those loads developed on Bolt Type TRT3-2 and TRT3-3. The possible reasons were attributed to the direction and impact of the horizontal stresses. Generally Bolt Type T3 has shown a higher load along the bolt in every position compared to Bolt Type T1.

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Figure 9.13. Load transferred on the bolt Type T1 installed at the travelling road in, Metropolitan Colliery
Figure 9.14. Load transferred on the bolt Type T3 installed at the travelling road in, Metropolitan Colliery
Figures 9.15 and 9.16 show the corresponding shear stresses at the bolt resin interface for both Bolt Types T1 and T3 respectively. The shear stress developed at the bolt resin interface was calculated using the following equations:

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

(9.4)

where;

\(\Delta \tau\) = Average shear stress at the bolt-resin interface,

\(F_1\) = Axial force acting in the bolt at strain gauge position 1, calculated from strain gauge reading,

\(F_2\) = Axial force acting in 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.

Shear stress sustained by the bolt - resin interface had almost the same magnitude in Bolt Types T1 and T3 located in the middle and right side of the roadway at approximately 1.1 MPa. However the magnitude of shear stress developed in the Bolt Type TRT3-3 at the left side of the roadway was nearly four times Bolt Type TRT1-3 (1.2 against 0.3). This difference could be attributed to differing profile configurations. This finding was consistent with the laboratory results found from pull and push results (see Chapter 4).
Figure 9.15. Shear stress developed at the bolt/resin interface of the Bolt Type T1, in Metropolitan Colliery.
Figure 9.16. Shear stress developed at the bolt/resin interface of the Bolt Type T3, in Metropolitan Colliery.
9.4.2. Appin Colliery

Figures 9.17 a and b show the overall load transferred on the Bolt Type T1 during the long wall period (numbered MT1-II and MT1-III). Figures 9.18 a and b show the overall load generated on the Bolt Type MT3-I and MT3-II, respectively. Bolts MT1-I and MT3-III were malfunctioned.

Figure 9.17. Load transferred on the Bolt Type T1, (a) middle of the belt road (b) close to the belt in Appin Colliery

Figures 9.19 and 9.20 a and b show the corresponding shear stresses at the bolt resin interface for both Bolt Types T1 and T3 respectively. As can be seen the
development of shear stress in Bolt Type MT3-I was maximum at around 0.72 m above the head. These stresses were equivalent to 6.3 MPa in Bolt Type MT3-I and 1.3 MPa in MT3-II. However, Bolt Types MT1-II and MT1-III at the same position developed 4.6 and 4 MPa respectively.

Figure 9.18. Load transferred on the Bolt Type T3, (a) middle of the road (b) rib side in Appin Colliery
Figure 9.19. Shear stress developed at the bolt/resin interface of the Bolt Type T1, in Appin Colliery (a) middle of the road (b) belt side
9.4.3. Comparison of load transfer in Bolt Type T1 and Bolt Type T3

Figure 9.21 shows the comparative load profiles on Bolt Types TRT1 and TRT3 in Metropolitan Colliery (i.e. rib side bolts). Bolt Type T3 experienced higher axial load compared to Bolt Type T1. They were 30.1 and 28 kN respectively, which agrees with the previous findings from the laboratory tests discussed in Chapter 4.

Figure 9.22 shows the axial load transferred on the Bolt Types MT1 and MT3 in different long wall positions in Appin Colliery. The Bolt Type T1 was subjected to a relatively higher axial load than Bolt Type T3. This may have been due to the effect of a cable bolt installed in the same row as Bolt Type T3 (close to the Bolt Type MT3-II), (see Figure 9.8). Also the fact that Bolt Type T3 was closer to the dyke by one metre may have influenced the load developed on the bolts compared to Bolt Type T1.
Figure 9.21. Load transferred on the Bolt Type T1 and T3, installed at the right side of the traveling road, Metropolitan Colliery
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Figure 9.22. Load transferred on the Bolt Type T1 and T3, installed at the middle side of the belt road, Appin Colliery

9.5. SUMMARY

The field instrumentation study demonstrated the significance of the surface profile configuration in influencing the load transfer at the bolt - resin interface. This finding agrees with already proven test results conducted on similar bolts in the laboratory and reported in Chapter 4 in this thesis. Bolt Type T3 with higher and wider profile spacing contributed a higher load transfer capacity of bolt - resin rock interaction than closer spaced and lower profiled Bolt Type T1.

The instrumented site with respect to the long wall face (i.e., the main gate at Appin and travel roadway at Metropolitan Colliery) was influenced the level of load
transferred along the bolt. The load generated in Appin (belt road) was four times greater than Metropolitan (travelling road) due to flanking stresses affecting the roof of the adjacent main gate roadway much more than over the travelling roadway. Also,

- Dyke location affected the load transfer levels at the Appin site.
- Cable bolts affect the load developed on the bolts located closer to it.
- The field study showed, in an equilibrium situation, that Bolt Type T3 offered higher shear resistance, which was also observed in the laboratory studies.

It is thus recommended that the field study be extended to include more tests on different sites so that the performance of bolts with different profiles can be examined in different stratification for selection for operational safety and economic benefits.