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Investigation into Roof Support Behaviour at Grasstree Mine

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INVESTIGATION INTO ROOF SUPPORT BEHAVIOUR AT GRASSTREE MINE

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ABSTRACT: The results of a recent investigation into roadway roof support behaviour using a Geophysical Strata Rating (GSR) based support design method are presented. This paper outlines details of a study of roof support behaviour at two instrumented sites at Grasstree Mine. The impact of differing support elements were investigated and tested against developments in roof beam analysis in order to optimise the support process.

INTRODUCTION

Modern methods of strata characterisation and modelling such as the Geophysical Strata Rating (GSR) have been successfully developed and implemented for longwall support assessment based on support density, stress conditions and convergence limits (Medhurst et al, 2014). Preliminary investigations into the application for roof support design suggest a similar principle may apply. Initial studies demonstrated the capabilities of a newly developed analytical model to quantify the relationship between support practice and roof convergence (Medhurst 2015).

The role of stress and the impacts of weaker roof are increasingly impacting on development rates and productive capability particularly at those sites nearing the end of mine life. The industry is therefore requiring site based tools to help drive change processes, aid decision making and improve Trigger Action Response Plans (TARPs). In this context it was proposed to test the capabilities of the new design approach as part of a broader program to optimise roof support at Grasstree Mine. A detailed geotechnical study was initiated that included comprehensive instrumentation and monitoring of a roadway in conjunction with trials of new ground support hardware.

ROOF CONDITIONS AT GRASSTREE

Figure 1 shows the level of convergence based on 4-anchor mechanical extensometer (Tell Tale) data along the Main headings at Grasstree Mine. A marked increase in roof convergence past 40 ct is evident in the plot. Roof support consisted of 6 x 1.8 m bolts at 1.3m spacing in the headings, with 2 x 6m point anchored Superstrands every 2.6m across the intersections up to 50 ct. This support density was generally adequate up to 40ct (+300m cover depth) with the exception of a few isolated areas whilst a four bolt pattern with row spacing up to 1.4 was successfully installed outbye of 30 ct in places (<275 m cover depth). From inbye 40 ct additional guttering was observed in both headings and cut throughs. This correlates with the transition to a thick laminated sandstone/siltstone roof, increasing mica content and cover depth reaching 325 m. A six bolt pattern on 1.3 m spacing became marginal from 45 ct inbye, with excessive remedial support required, particularly across the cut throughs and intersections, due to excessive guttering, bagging and centreline cracking.

Over time the Grasstree roof support system evolved to shorten bolt row spacing to 1m and reduce cable length to 4 m however these are at minimum 75% resin encapsulation. This system was very effective in the 800 s series panels and up to 904 panel on the northern side of the mine. However at cover depth exceeding 350 m (905MG and beyond) this support regime also became marginal in places, even with Superstrands installed at 1 m row spacing. This triggered the installation of post groutable

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cables on advance and also quite often remedial support. Both of these support practices severely impeded development advance rates.

It was decided to find a stiff high capacity cable support that could be installed by hand at the face with a resin anchor overlapping the bolted horizon. This led to the discovery of the Goliath cable. The vision was to not only be able to space the cable supports further apart and achieve the same or better results, but to also potentially install Goliaths at 1 m row spacing replacing the need for post groutable cables. A proposal to undertake a support and instrumentation trial in MG906 was developed.

![Figure 1: Roof convergence in Mains at Grasstree Mine](image1)

The Geophysical Strata Rating (GSR) system has been used by Grasstree personnel to assist with design and planning since late 2013. This system is now the preferred method for characterising the strata, with particular emphasis placed on support optimisation due to both increasing cover depth and longwall retreat rates. In current development panels GSR for the immediate 3 m of roof typically ranges from 50–65 as shown in Figure 2.

![Figure 2: Median GSR over 3m of roof and GSR/σ\(_H\) at Grasstree Mine](image2)

Figure 2 also shows the GSR to horizontal stress ratio. Previously, a relationship between the onset of roof instability and GSR:σ\(_H\) has been established with a GSR:σ\(_H\) = 3 being considered a threshold level. Figure 2 also shows the GSR to horizontal stress ratio. Previously, a relationship between the onset of
roof instability and GSR: $\sigma_H$ has been established with a GSR: $\sigma_H = 3$ being considered a threshold level. This ratio is just above that level and a check on those ratios suggests that roadways with a stress concentration factor $> 1.2$ would reach this stress threshold. Increased levels of roof convergence are now being experienced in the deeper parts of the mine leading to an increase in installed roof support density. This suggests that stress related damage is a contributing factor to the observed poor roof conditions.

**MONITORING PROGRAM**

**Geotechnical Setting**

A monitoring site was chosen inbye of 4 ct in the travel road of MG906. Figure 3 shows the monitoring site and the GSR analysis for the borehole (ECC1079) closest to the monitoring locations. Detailed inspection of the GSR data shows that the immediate roof is generally strong and overlain with a weaker siltstone unit. In some areas however the roof is known to be highly anisotropic with weak bedding or micaceous zones present.

![Figure 3: Monitoring location showing cover depth with borehole analysis](image)

Stress measurements were also completed for the study in Hole ECC1073 located just outbye of 4 ct and are summarised in Table 1 (Sigra, 2015). The results suggest a stress ratio in the range $H:V = 1.5$ to $1.9$ in the overlying roof strata.

**Table 1: Stress measurement results**

<table>
<thead>
<tr>
<th>Depth (m)</th>
<th>Location</th>
<th>Material</th>
<th>Angle of $\sigma_1$ (°)</th>
<th>$\sigma_1$ (MPa)</th>
<th>$\sigma_2$ (MPa)</th>
<th>$\sigma_V$ (MPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>377.0</td>
<td>GC Roof</td>
<td>Siltstone</td>
<td>42.2</td>
<td>15.6</td>
<td>10.3</td>
<td>9.4</td>
</tr>
<tr>
<td>380.0</td>
<td>GC Roof</td>
<td>Sandstone</td>
<td>49.8</td>
<td>14.5</td>
<td>9.5</td>
<td>9.5</td>
</tr>
<tr>
<td>382.96</td>
<td>GC Roof</td>
<td>Siltstone</td>
<td>32.2</td>
<td>17.9</td>
<td>10.7</td>
<td>9.6</td>
</tr>
<tr>
<td>390.02</td>
<td>GC Floor</td>
<td>Siltstone</td>
<td>39.6</td>
<td>11.3</td>
<td>7.9</td>
<td>9.75</td>
</tr>
</tbody>
</table>
Roof Support and Instrumentation

A key aim of the monitoring program was to evaluate roof support performance for typical patterns used at Grasstree, assess the potential for alternative support strategies and devise a method for predicting tolerable convergence based on support density and rock mass competency (GSR). The primary roadway roof support at Grasstree consists of 1.8 m X Grade roof bolts, 4.1 m Superstrand cables and either 6.2 m or 8.2 m MW9 Megastrands. One aspect of this study was to investigate the use of Goliath cables in place of Superstrands. A summary of support properties is shown in Table 2 and the instrumentation layout in Figure 4. It should be noted that the Goliaths are comprised of smooth wires and the Superstrands are indented.

Table 2: Support properties

<table>
<thead>
<tr>
<th></th>
<th>X Grade Bolt</th>
<th>Superstrand</th>
<th>Megastrand</th>
<th>Goliath</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length (m)</td>
<td>1.8</td>
<td>4.1</td>
<td>6.2/8.2</td>
<td>4.1</td>
</tr>
<tr>
<td>Diameter (mm)</td>
<td>21.7</td>
<td>21.8</td>
<td>31</td>
<td>28.6</td>
</tr>
<tr>
<td>Hole diameter (mm)</td>
<td>28</td>
<td>28</td>
<td>42</td>
<td>35</td>
</tr>
<tr>
<td>Minimum UTS (t)</td>
<td>30</td>
<td>58</td>
<td>62</td>
<td>99</td>
</tr>
</tbody>
</table>

Additionally, tell-tales were installed at the two sites. Readings from the instrumented bolts were used to determine axial force, axial strain, bending moment and bending strain in the primary support horizon.
(SCT 2000). Shear strips were installed to gauge the extent of horizontal movement and strain within the supported roof interval and load cells were installed to measure the total load at the base of the tendons. Sonic extensometers were installed to measure the vertical movement within the roof up to 8m above the coal seam and were comprised of 20 anchors. Instrumentation was installed by a combination of Grasstree, SCT and PDR personnel.

**STABILITY ASSESSMENT**

Another objective of the project was to test the capabilities of the roof support analytical model (Medhurst 2015). The two support regimes were therefore assessed prior to the trial in order to evaluate the potential impact of increasing the spacing from 1 m to 2 m using the higher capacity Goliath cables. The analysis shows predicted outcomes based on a range of support patterns using data from Hole ECC1079. The examples are based on a fixed cantilever model. Blue curves apply to initial X Grade bolts installed in roadways. Green and pink curves apply to combined strands and the X Grade bolts in the roadways. The red curves apply to intersections. Figure 5 shows the ground response for the Superstrand pattern and Figure 6 for the Goliath pattern.

In general, replacing Superstrands with Goliaths at 2 m spacing in roadways will produce a similar overall support density, but would reduce the serviceability by about 10 mm. In other words there would be 10 mm less to work with in the TARPs with the Goliath support installed, i.e. note the difference in serviceably limit as predicted by the analytical model. This is the consequence of having a stiffer, higher capacity tendon installed at a wider spacing. In general, it is suggested that provided the beam end constraints are preserved then roof convergence levels would be kept to 30 mm in the roadway regardless of the support type used.

Figure 7 shows an equivalent plot for the Goliaths based on a propped cantilever beam model. Note that roof convergence levels would be predicted to be just over 40 mm at 4 m softening height in the roadway. Note also how the intersection reaches its serviceable limit at about 70mm at a 6 m softening height. The differences between Figures 6 and 7 show the influence of stress related damage and/or strata relaxation in the roadway.

In general the stability assessment indicated that Superstrands could be swapped out with the Goliaths at the broader spacing, but the roof would be less tolerant to increased levels of roof convergence. In other words, the analysis suggests that the height of softening would reach the same levels of convergence as the Superstrands but with 10mm less roof movement with the Goliath pattern.
Site 1 - Superstrands

As is the case with many underground monitoring programs, problems with data capture and measurements were encountered. In particular, there were issues with the strain bridge monitor used to acquire readings from the instrumented bolts and the shear strips. This led to a large number of missed results, mostly around the centre of the bolts. The shear strips were more resilient due to the use of four separate readings for one strip, however some data was still lost. The sonic extensometer data is shown.
in Figure 8. The results show up to 27 mm of movement on the left hand side and less than 5 mm on the right. Some distinct saw tooth profiles are also present in the data, mostly on the left that are interpreted as the influence of shear movements.

Figure 8: Roof displacements for Superstrand pattern

Figure 9 shows axial force (kN) at Site 1 at 48 days after installation. For the purpose of the contours both rows of bolts (4/2 pattern) have been flattened onto a single plane. The pattern shown here is indicative of all readings at the site, where force is concentrated down the left hand side of the roadway along the stress biased side. Particularly high readings were measured in the out-of-plane (mid-mesh) bolt in the staggered pattern at 0.75 m from the rib. A noticeable bias to the left in roof deformation was also observable in the roadway that is consistent with the measured stress orientation.

Figure 9: Axial force in roof bolts for Superstrand pattern

Figure 10 shows the variation in axial load with time along the staggered bolt. The plot on the left shows axial force at a particular location along the bolt. A consistent increase is observed at the 280 mm location just above the roof horizon, whilst it is relatively constant at the 460 mm level albeit at a higher load. A slow decrease is detected in the upper half of the bolt. The distribution is shown on the right and is plotted relative to time and face position (instrumentation was installed at 73 m). The load increase in the lower 1 m of the bolt over time is evident. The corresponding results from load cell monitoring of the Superstrands is shown in Table 3. The capacity of the load cell (25 t) was reached on the left hand side of the roadway after the face advanced approximately 7m inbye the instrumentation site. Load monitoring in the bolts and Superstrands shows distinct evolution of build-up over the first three days as the face advanced past the “square”, i.e. 5 to 6 m. The shear distribution for the left and right side of the roadway is shown in Figure 11.
Table 3: Load cell results for Superstrand pattern

<table>
<thead>
<tr>
<th>Face Position</th>
<th>LHS (tonnes)</th>
<th>RHS (tonnes)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Install (73m)</td>
<td>13.8</td>
<td>11.0</td>
</tr>
<tr>
<td>75m</td>
<td>15.1</td>
<td>11.0</td>
</tr>
<tr>
<td>76m</td>
<td>17.50</td>
<td>11.0</td>
</tr>
<tr>
<td>76.5m</td>
<td>19.0</td>
<td>11.0</td>
</tr>
<tr>
<td>76.5m</td>
<td>22.5</td>
<td>12.0</td>
</tr>
<tr>
<td>79m</td>
<td>24.8</td>
<td>12.5</td>
</tr>
<tr>
<td>80.5m</td>
<td>~26 *</td>
<td>12.8</td>
</tr>
<tr>
<td>80.5m</td>
<td>~28 *</td>
<td>13.5</td>
</tr>
<tr>
<td>92m</td>
<td>~28 *</td>
<td>14.8</td>
</tr>
<tr>
<td>5 Cut-through</td>
<td>~30 *</td>
<td>15.0</td>
</tr>
</tbody>
</table>

*Load cell maxed out at 25000kPa, estimated from dial position.

A distinct shear zone is present at the 2.5 m to 3 m horizon on the left side, and at 0.95m to 1.35 m on the right with a smaller amount of shear at about 2.5 m. When compared with the sonic extensometer data, the results suggest that horizontal movements up to about 3.5 mm occurred between the 3 m and 2 m horizons, which were measured at about 7 mm in the sonic extensometers. The results indicate that about 50% of the movement detected by the sonic extensometer associated with the shear plane was horizontal and not vertical.
Site 2 - Goliaths

At the second test site a significant amount of data was lost and results are limited in this area. Nevertheless some repairs were made during the monitoring period that allowed enough results to be obtained to provide a measure of roadway behaviour. Readings from the sonic extensometer were not affected as it uses a different monitoring device. Figure 12 shows the sonic extensometer data for the Goliath pattern and Figure 13 shows the corresponding shear strain distributions. The results show a bias to the left as was the case for Site 1. However the magnitude of the displacements and the degree of shear within the overlying roof strata was increased, with maximum roof displacements increased by approximately 15 mm from the Superstrand pattern. It should also be noted that the bolt tensioner was not working correctly when the Goliaths were installed (the wedge was observed to tighten after the 1 m cut) which may have contributed to increased convergence levels in the lower part of the roof. Unfortunately limited data was available for the strain gauged bolts, but sufficient load cell data was available to assess the effect on the Goliath cables and is summarised in Table 4.

![Figure 12: Roof displacements for Goliath pattern](image1)

![Figure 13: Shear strain distribution for Goliath pattern](image2)

**Table 4: Load cell results for Goliath pattern**

<table>
<thead>
<tr>
<th>Face Position</th>
<th>LHS (tonnes)</th>
<th>RHS (tonnes)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Install (92m)</td>
<td>8.2</td>
<td>6.0</td>
</tr>
<tr>
<td>93m</td>
<td>11.0</td>
<td>7.0</td>
</tr>
<tr>
<td>93m</td>
<td>14.0</td>
<td>8.0</td>
</tr>
<tr>
<td>94m</td>
<td>17.0</td>
<td>9.0</td>
</tr>
<tr>
<td>96m</td>
<td>18.8</td>
<td>11.0</td>
</tr>
<tr>
<td>98m</td>
<td>19.0</td>
<td>11.0</td>
</tr>
<tr>
<td>125m</td>
<td>24.0</td>
<td>17.0</td>
</tr>
</tbody>
</table>

Again a bias towards the left is present which could be observed underground. The most distinct feature however was a noticeable bulging of the strata between the rows of Goliaths at 2 m spacing. An
increase in roof deformation could therefore be observed between the cables, which are reflected in the sonic extensometer data. The row spacing of the cables therefore has an influence on roof deformation and roof stiffness. It also appears that more shear planes could develop within the cable horizon as a result of the wider spacing. Interestingly this does not appear to have created additional load on the tendons.

The Goliath pattern showed moderate levels of loading generated within the cables but with a higher degree of roof deformation when compared to the Superstrands. Closer comparison of the shear and extensometer data suggests the development of several shear planes through the cabled horizon. The results suggest that a significant proportion of the measured vertical displacement would be from horizontal movements on these shear planes, it is estimated in the range of 25% to 50%. However despite the difference in roof behaviour between the two support patterns, the overall level of damage and support loading remained within acceptable levels for the Goliath pattern.

Planning and Design Implications

A marked increase in roof deformation was measured where the Goliath cables were installed when compared to the Superstrands. In contrast the Superstrands showed higher measured loads and appeared closer to failure. The load was therefore distributed differently through the roof with each pattern. Both patterns have similar installed support density and the trial areas are only about 25 m apart. Hence the wider spacing of the Goliaths appears to have had an impact on roof deformation and associated support loading. Interestingly this particular case shows that the difference in roof behaviour would not have been reflected in an assessment based on support density and rock mass quality alone; and highlights the important role of TARPs in strata management.

The initial stability assessment suggested that there was about 10mm less to work with in the TARPs with the Goliath pattern. The monitoring program has broadly confirmed this conclusion, but the assessment has probably underestimated the degree of roof convergence in the Goliath pattern. An important observation however is the amount of horizontal movement over multiple horizons, which has contributed to the increase in measured convergence.

The propped cantilever model for the Goliath pattern does match the measured response more than the fixed beam analysis for the left side of the roadway. Only minor guttering was observed in the roadway however, suggesting that the roof beam is probably in some transient state between fixed and propped. There is also a trade-off between tendon spacing, strata damage and roof deformation as a result of a change in roadway behaviour with the different pattern. The new analysis method partly addresses the issue but not completely. Further work is required on the assessment of roof stiffness with varied tendon spacing and/or its impact on the ability to develop shear planes in the roof. The ability to assess highly bedded or micaceous roof in the GSR assessment is also under consideration.

The use of Goliaths at the wider spacing has been successful in that convergence levels, support element loading and height of softening is maintained within acceptable levels whilst the number of support elements is reduced in the development cycle. It also appears that such changes will require tailoring of the TARPs once experience with the new support is gained. This is an important outcome as the initial TARPs might need to be re-assessed based on the support pattern i.e. design and not just a change in the ground conditions. Continued optimisation appears feasible with the use of higher capacity tendons. Further monitoring will be undertaken during longwall extraction so that the impact of stress changes can be assessed.

CONCLUSIONS

An instrumented roadway trial of two sites at Grasstree Mine was undertaken to evaluate the potential for using a new high capacity tendon support at reduced density. The stability analyses and subsequent roof support trial proved successful in being able to reduce the density by increasing the spacing between cables. A measured difference in roof behaviour was however detected, with a greater degree
of shearing or horizontal movement in the roof leading to increased roof convergence for the wider pattern. The trial has provided some important insights for further development of roof support behaviour models as well as highlighting potential operational impacts on TARPs. The degree of roof movement is an important parameter in the management of roof stability and this work has provided new information on the interplay between support practice, roof conditions and stress. In this particular case, the change in roof behaviour was not sensitive to the installed support density but on other parameters such as bolt placement and spacing. It would appear that further optimisation of roof support will require assessments that consider these parameters. This is the subject of further research.

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