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ANALYSING THE EFFECTIVENESS OF THE 1750 TONNE SHIELDS AT MORANBAH NORTH MINE

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ABSTRACT: Moranbah North Mine has a challenging geotechnical environment that historically resulted in cavity formation on the longwall face with its an associated reduction in productivity. Due to the complex geology at the mine, the increased depths of cover in future panels and the aging of the previous 980 t shields, longwall face stability became a concern. In order to ensure effective strata control in future panels, a new set of 1750 t powered supports were installed into the longwall 108 panel in 2009. These shields were, and still remain, the highest rated capacity shields in the world. This paper presents the results of an investigation into the effectiveness and necessity of the new powered supports. The investigation was undertaken in the form of a comparative analysis to determine the relative effectiveness of the two sets of different capacity shields by analysing the performance of the shields in panels that were directly adjacent and, subsequently, subject to similar conditions. Anglo American has plans to commence two additional longwall mining operations in the same region and the outcome of the investigation will allow the suitability of the larger capacity shields to be determined for the future operations.

INTRODUCTION

Strata control is a fundamental issue in underground coal mining as strata that is destabilised or has insufficient support can lead to events such as roof falls and formation of cavities. The primary area of concern is at the longwall face due to the face being subject to a dynamic, complex and constantly changing stress field. Advancement in mining technology has allowed for increases in mining depths, face heights and face lengths which, in turn, have resulted in the progressive increase of the maximum available powered supports.

In 2009, Moranbah North Mine (MNM) installed a new face of 1750 t longwall shields into the start of the 108 panel in order to combat various strata issues encountered at the mine including weak roof, overlying massive strata and increasing depths of cover. The 1750 t shields replaced 980 tonne shields due to concerns about their aging and insufficient support capacity.

An investigation was undertaken to determine the effectiveness and necessity for the new 1750 t shields. A comparison was made between LW108 and LW107 so that the relative effectiveness of the 1750 t shields could be determined. The two panels are directly adjacent to each other and were subject to similar conditions, hence making them ideal for a comparative assessment. The factors investigated included:

- Shield leg pressures;
- Cavity occurrences;
- Lost time due to strata control issues;
- Lost time due to shield issues;
- Time spent at or above yield pressure; and
- Shield performance in geological hazard zones.

POWERED SUPPORTS AND FACTORS AFFECTING FACE STABILITY

Longwall supports are designed to confine and control the fractured roof as the shearer cuts the coal. The supports must laterally confine high angled fractures to prevent dropout in front of the canopy. In order to improve the integrity of the immediate roof and to create a goaf break off line, the supports must

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also vertically confine the fractured strata to allow the transfer of the vertical stress into the roof. The creation of the goaf break off line behind the supports is important to prevent the caving mechanism progressing over the canopy towards the face. The effectiveness of the shields in controlling the caving environment about the face, therefore, depends on the ability of the shields to transmit stresses into the roof strata (Gale, 2009). There are numerous factors which can affect face stability with the factors that were considered in this investigation including:

- Set and yield pressures;
- Periodic weighting;
- Production delays; and
- Depth of cover.

Set and yield pressures

Hydraulic fluid is pumped into the leg chamber as the shield is set against the roof and the setting valve is closed and the fluid gets locked in. The pressure of the fluid at which the valve is closed is the working pressure of the pump and is referred to as the setting pressure (Deb, *et al.*, 2000). Once the support has been set, roof convergence will occur over time and the fluid in the leg will be compressed, the fluid pressure will increase and the leg cylinder diameter will expand until the yield pressure is reached. Once the yield pressure is reached, the leg will yield as designed.

The yield pressure is the maximum pressure allowed in the bottom stage of the leg cylinder before the hydraulic cylinder and the pistons become compromised (Mitchell, 2009). During yielding, hydraulic fluid is released from the leg cylinder and the leg subsequently lowers a small amount during the yield event until the resetting pressure of the valve is reached. The resetting pressure will determine the amount of fluid lost and the amount of closure. Yield valves typically have a resetting pressure of 90% or higher, which equates to a 10% decrease in pressure before the valves closes (Barczak and Tadolini, 2007). The leg pressure will then gradually increase again due to continued roof convergence until the yield pressure is again reached and the cycle is repeated (Mitchell, 2009).

Roof deterioration between the canopy tip and the longwall face generally occurs after more than three yield events, with the severity of the deterioration increasing with the number of yields (Trueman, *et al.*, 2010). A shield with sufficient support capacity should not be in yield more than 5-10% of the time.

Periodic weighting

Periodic weighting of the powered supports occurs when the longwall face is subjected to recurring cycles of overhang and breakage of strong strata in the immediate and main roof. The strong strata tends to cantilever over the goaf, resulting in periodic weighting of the supports. The frequency and intensity of periodic weighting is a function of the roof strength and thickness, the characteristics of the goaf, the distance of the strong stratum from the seam and the frequency of jointing. The periodic weighting peak occurs immediately before the caving of the strong stratum when the length of the cantilevered strata into the goaf is at a maximum (Agapito, *et al*, 1998).

Support overloading as a direct result of periodic weighting can result in yielding of the supports. Supports are most likely to yield as a result of period weighting at the peaks of the periodic weighting cycle with yield events also being probable during periodic weighting intervals when cycle times are relatively long. Multiple yield events in a single load cycle have been shown to cause roof control problems and are typically indicative of supports that are being periodically overloaded (Trueman, *et al*, 2010).

Production delays

The results of an analysis of real-time shield pressures conducted by Deb *et al.* (2000) showed that leg pressure increases rapidly within the first few hours after longwall downtime and then increases more gradually. When the cutting operation first experiences a delay, elastic or elasto-plastic deformation may occur in the roof which will result in roof-to-floor convergence and will cause a rapid increase in loading on the shield. Once the roof has settled onto the support canopy, the loading on the shield may gradually increase due to the shields response to creep deformation of the roof. This pressure increase can be large enough to cause shield yielding within hours of the longwall ceasing operation (Deb, *et al.*, 2000). Roof cavities as well as any strata stability issues may, therefore, be a direct result of production delays and not due to insufficient support capacity.

Depth of cover

Medhurst (2005) stated that although increasing cover depth generally results in a higher shield loading, modern capacity shields are sufficient to adequately control the roof in deep longwalls with everything else being equal. Hill (2006) also claims that the rate of powered support convergence tends to increase with increasing depth which suggests that at increased depths the supports approach yield more rapidly and ground conditions will tend to deteriorate with all other factors being equal. Hill (2006) suggests that the main cause of this effect would be the higher vertical abutment loading.

A geotechnical assessment conducted at MNM (Medhurst, 2006) determined that a combination of overlying massive strata, weak immediate roof and the presence of a rider seam in some areas of the mine resulted in the longwall face being continually operated at its limit. The assessment determined that under such working conditions, there existed little room for error and, as such, the impact of increasing depth of cover in future panels needed to be taken into account as the conditions were predicted to become more arduous at greater depths. This was a vital issue with respect to this investigation as one of the principle reasons for the shield upgrade at MNM was the increasing depths of cover due to the concern that the older shields had insufficient support capacity to cope with the additional stresses at the increased depths.

MORANBAH NORTH MINE GEOLOGICAL AND SHIELD INFORMATION

The geological conditions and rock mass characteristics at a mine site have a significant effect on the overall stability of the mine and the required support capacities. In order to fully assess the effectiveness of the new 1750 t shields, the relevant geological conditions needed to be assessed. The factors that were considered include:

- Lithology;
- Coal seams and ply splits;
- Depth of cover; and
- Faults.

Depth of cover

At MNM the seam dips to the east at 3 to 5° and the depth of cover increases to the east with LW108 being situated at approximately 300 m depth. Future panels will increase to depths exceeding 400 m. This increasing depth of cover was one of the principle reasons for the purchase and installation of the new 1750 t shields with depths of more than 220 m showing an increase in cyclic loading and face cavities. The mine layout with depth contours can be seen in Figure 1.

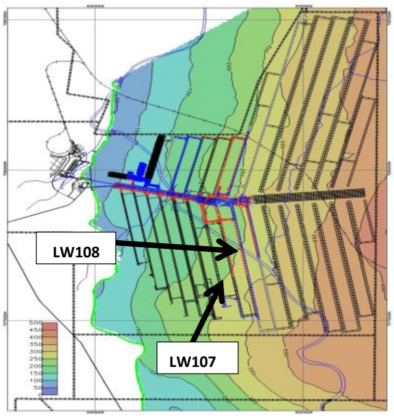

Figure 1 - Moranbah North Mine layout and depth contours

Sandstone channels

The presence of strong strata in the immediate or main roof such as sandstone channels can lead to periodic weighting events. The geology at MNM consists of several such sandstone channels which have led to numerous weighting events resulting in the yielding of the shields. The experienced gained at MNM indicated that in general, only the sandstone channels of more than 5 m in thickness and more than 30 MPa in strength will result in support issues (Laws, 2011). There are three main sandstone channels within the overburden at MNM that are of concern MNM, namely, MP/MR20, MP/MR42 and MP/MR41. The sandstone channels generally also cause normal faults to develop directly below the channels.

Faults

Faults which exist in the immediate roof and overlying strata can impact significantly on ground stability as they can act as planes of weakness leading to excessive fracturing and roof falls. A large strike slip fault is present at MNM that runs approximately parallel to the working face at the southern end of the panels and has caused numerous support issues (Laws, 2011).

Seam Ply 1-2 split

There is a section of the mine where the seam Ply one splits away from Ply two by a distance ranging from 0.2 to 1 m. The area between the main seam and the top ply consists mainly of a weak siltstone material and, subsequently, due to the increasing area of this material as a result of the ply split, the strength of the immediate roof is significantly decreased. Ply one is completely removed from the GM seam thickness when the Ply one to two parting thickens to over 0.2 m (Laws, 2011). This decrease in roof strength results in a reduced ability to accommodate any horizon control issues.

Goonyella Middle Rider Seam split

The Goonyella Middle Rider (GMR) Seam splits off the top of the Goonyella Middle (GM) Seam towards the south and east sides of the lease area. When the split is between 1-2 m thick, major roof control issues have historically been experienced. When the GMR seam is coalesced with the main roof, the material in the interburden has an approximate strength of 5 MPa and consists of a mudstone/siltstone laminate interspersed with bedding plane shears. As the GMR split increases, the thickness of this weak zone also increases and results in the supports being unable to provide adequate confinement. As the GMR splits away to a distance of more than 2 m, however, the material strength increases and the GMR split becomes less of a geotechnical hazard (Laws, 2011).

1750 t shields

A feasibility study conducted in 2006 (Medhurst, 2006) concluded that due to the combination of overlying massive strata, weak immediate roof, the presence of the GMR rider seam and increasing depths of cover, the shields being utilised at that time (with a capacity of 980 t) would provide inadequate ground support for future panels as they were already constantly operated at their limit. The study furthermore concluded that in order to provide adequate roof support and stability for deeper panels, 1750 t capacity shields with a width of 2 m would be required. The project was approved and 151 1750 t capacity shields were installed into LW108 in 2009.

Longwall visual analysis software

Longwall Visual Analysis (LVA) software collects and stores real time data from the longwall shield legs. The leg pressures of every shield installed on a longwall face are recorded every minute as mining progresses. The software has a number of functions that are useful in determining the effectiveness of the shields with the Time Weighted Average Pressure (TWAP) function being used for this investigation. The TWAP function calculates the average leg pressures for each leg of each shield for every load cycle. The average pressure is calculated from when the shields are initially set to when the shields release at the end of the load cycle before advancement. Each leg pressure value is recorded against the corresponding chainage value.

DATA ANALYSIS

Longwall sections used in analysis

In order for the comparative assessment to be as accurate as possible, only the sections of the longwalls which were directly parallel to each other were used. As LW108 was significantly longer, this required starting the analysis of LW108 at the install point of LW107. Analysing sections outside of this region would have resulted in inaccurate results. This process was necessary for a number of reasons including:

- Commissioning of the new longwall gear resulted in a very slow start with some shifts only accomplishing a couple of shears;
- There were problems initially with loading the coal onto the AFC which led to the inclination of the AFC and significant horizon control issues; and
- In and around the LW107 install road, LW108 encountered a double stress notch which caused additional delays due to the requirement of additional support.

For the sections being analysed, LVA data was unavailable or corrupt for the start of LW107 and the end of LW108. As such, when this data was required for the analysis, particularly for the analysis of shield performance in geological hazard zones and lost time, deputy delay reports were used to find the required information.

Longwall visual analysis data

As LVA outputs values are recorded on an hourly basis, for each individual shield, multiple leg pressure values were recorded against the same chainage value. In order to condense the data into a more manageable data set whilst still accurately representing the pressure values for each shield, an Excel macro was used to sort the data. The macro sorted the data by taking an average of all the pressure values for a single shield with the same chainage values to give a single pressure value.

After the data had been sorted, the data was then condensed into three columns representing easting, northing and pressure values. In order for accurate coordinates to be assigned that would represent the real-time location of the chainage values according to the mine plan, the shield canopy widths and the angle of the longwall panels had to be taken into account. For the canopy widths, the averaged pressure values were taken to be located at the centre of each shield so, subsequently, the centre to centre distance of each shield had to be added onto each x-coordinate.

In order to allow the data to be aligned accurately with the longwall panels on the mine plan, the coordinates needed to be altered to allow the bottom left hand corner of each LVA data set to be aligned with the right hand corner of each longwall panel at the point in each panel which corresponds to the start of the panel section being investigated. These points can be seen in Figure 2. Using these identified points, the macro adjusted the assigned coordinate values by adding the distance along the length or width of the longwall panels according to the points of rotation. Since the longwall panels are positioned at an angle of approximately 10° west of north, 100° was used as the point of rotation.

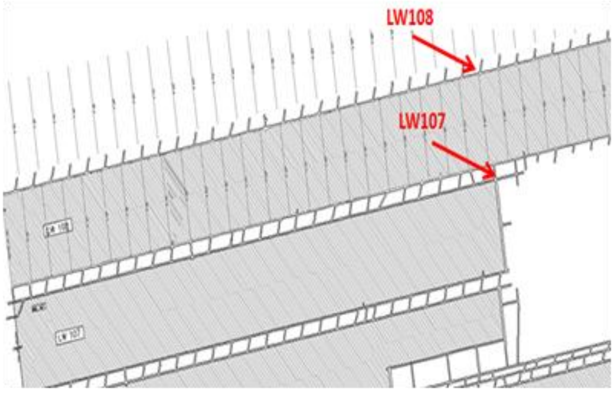

Figure 2 - Data analysis start points and points used for LVA data rotation

Leg pressure contours

Once the manipulation of the LVA data was complete, the data was imported into Surfer and contour maps were created for each longwall panel. The red areas represent low pressure areas and are indicative of the presence of cavities. The contour maps for LW107 and LW108 can be seen in Figure 3. The contour maps were then exported into AutoCAD and overlayed onto the mine plan.

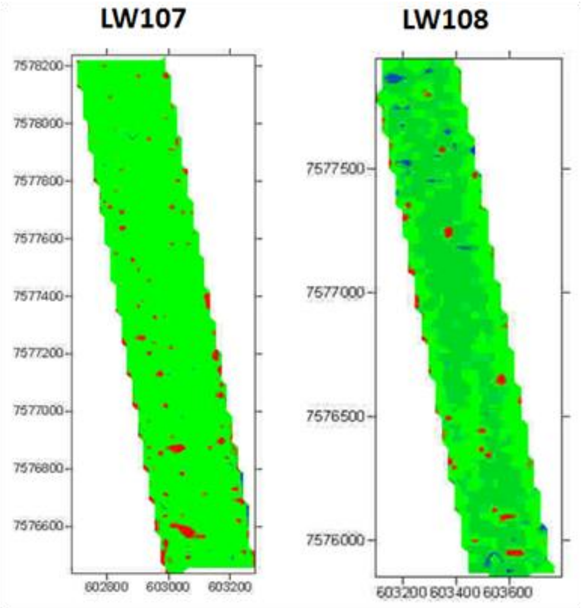

Figure 3 - Leg pressure contours with low pressure regions indicated in dark or red areas

Geological hazard map

Once the leg pressure contours had been overlayed onto the mine plan, mine geological data was used to create a Geological Hazard Map (GHM) so that shield performance in high geological hazard zones could be evaluated and compared. The GHM can be seen in Figure 4. The geological features that were included in the GHM include the following:

- The GM1 - GM2 Ply split zone of over 0.2 m parting thickness;
- The GMR split zone between 1 m and 2 m;
- Major faults; and
- Potential weighting zones.

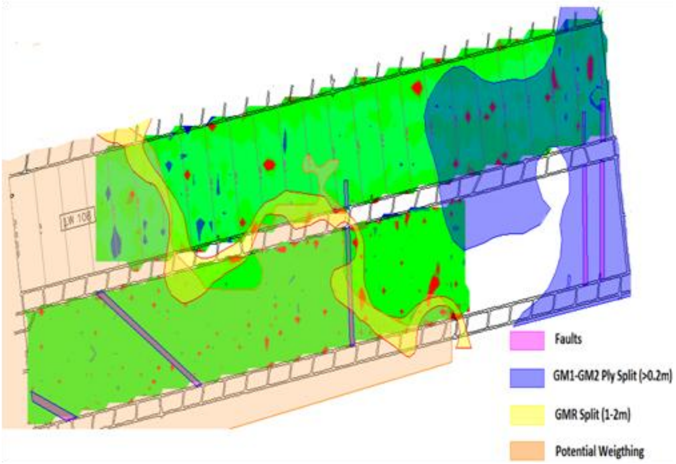

Figure 4 - Geological hazard map with pressure contours

Panel delays due to cavities and shield issues

In order to determine the effectiveness of the shields, the amount of time lost due to cavities and shield issues were also analysed to give a more quantitative result. Pivot tables were created in Microsoft Excel using the deputy delay reports for each panel to identify the time lost. The results of the analysis were cross-checked with the mine geotechnical engineers to ensure results were as accurate as possible and were reflective of actual circumstances.

Eliminating data inaccuracies

Prior to the analysis of the LVA data, all data which could result in inaccurate results had to be eliminated. The raw LVA data had to be filtered to ensure there were no zero values present in the data set. This process was necessary as the presence of zeros in the LVA data caused inaccuracies in the manipulated data results as the zero values significantly lowered the averaged pressure values and caused the generated contour maps to indicate low pressure regions where, in reality, none may have existed. The presence of zeros in the data set was attributed to a number of factors; shield mechanical issues, shield electrical issues and issues with LVA.

The rows in the raw data which contained missing values also had to be deleted before the data manipulation commenced as the data manipulation process is such that any cells with no values are automatically assigned zero values. This similarly caused problems in the generated contour maps.

RESULTS AND DISCUSSION

Shield effectiveness determined from leg pressure contours

The generated leg pressure contours show low pressure regions of pressures less than 250 b in dark/red areas. These low pressure regions indicate the presence of cavities and, as such, highlight the shields general performance throughout the panel. From Figure 3 it can be seen that LW107 had significantly more low pressure regions than LW108. By cross-checking the dates corresponding to the locations of the low pressure regions with deputy delay reports, the number of low pressure regions on the contour maps which resulted in lost time due to cavities was able to be determined.

It was found that for LW108 there were only six cavity occurrences which resulted in lost time with four of these cavities occurring in the tailgate. For LW107, however, it was found that there were 38 cavities resulting in lost time with four of these cavities occurring in the tailgate.

The remaining low pressure regions which were not found to have resulted in lost time due to cavity control can be attributed to shield mechanical issues or shield electrical issues. It can be seen from the determined values that LW108 performed significantly better in terms of preventing cavity occurrences than LW107. A summary of the results can be seen in Table 1.

Table 1 - Low pressure regions from contour maps

Low Pressure Regions	LW107	LW108
Total	87	27
With lost time	38	6
With lost time in the tailgate	4	4
With lost time in the face	34	2

Shield performance in geological hazard zones

By analysing the leg pressure contours in correlation with the constructed GHM, the performance of both sets of shields in high hazard zones was compared and analysed. As can be seen from Figure 4, the end of LW108 and start of LW107 were missing from the analysis due to the unavailability of the data. As such, for the purpose of assessing shield performance in high hazard zones, deputy delay reports were used to identify any cavity occurrences in the regions with missing data. The actual number of cavity occurrences in these circumstances could not be explicitly stated due to the deputy delay reports not stating explicitly whether the delays due to cavities recorded on consecutive days were due to a continuation of a single cavity or due to multiple separate cavities.

Figure 4 shows that the LW108 shields performed significantly better in terms of strata control in all high hazard regions with the ply split zone appearing to pose the most difficulty for the shields. A summary of the results can be seen in Table 2.

Table 2 - Shield performance in geological hazard zones

Hazard Zone	Number of Low Pressure Regions	
	LW107	LW108
Fault zone	multiple	multiple
Ply split zone	multiple	multiple
GMR split zone	9	1
GMR split and weighting zone	6	3
Weighting zone	41	1

Time lost due to cavities

Using deputy delay reports, the amount of time lost due to cavity control issues in each panel was determined and subsequently compared. It was found that LW107 had more hours lost due to cavities than LW108 with LW107 losing 170 h while LW108 lost 141 h. When taking into account the significant difference in cavity occurrences in each panel, the difference in lost time is not as large as would be expected.

Further filtering of the deputy delay reports in correlation with mine site geotechnical advice, however, allowed the total cavity occurrences for each panel to be separated into tailgate cavities and longwall face cavities. This was a necessary process as the effects of the double stress notch encountered in LW108 extended to approximately 100 m or one cut-through past the install face of LW107. The effects of the stress notch resulted in major tailgate support issues in LW108 and required additional tailgate support to be installed which caused significant delays. Large unmapped faults which ran perpendicular to the longwall face and parallel to the tailgate were also encountered in LW108 which led to stoppages due to tailgate support issues. Additional delays were also encountered in LW108 due to gas levels, not experienced in LW107, preventing immediate entry to the tailgate for the installation of secondary support for the longwall retreat.

Taking into account the intense tailgate conditions unique to LW108, and in order to provide an accurate comparative assessment, the amount of lost time due to cavities in the tailgate for both panels should not be included in the final assessment of the shield effectiveness. The final assessment will, therefore, focus only on strata control issues relating directly to the longwall face. A summary of the results can be seen in Figure 5.

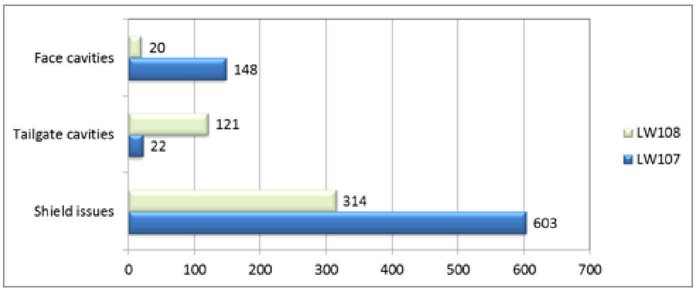

Figure 5 - Time lost due to strata control and shield issues

Time lost due to shield issues

Again using the deputy delay reports, the amount of time lost due to shield issues in each panel was able to be determined and subsequently compared. The shield issues incorporate all mechanical, electrical and operational issues. The lost time due to shield issues in both panels can be seen in Figure 5.

As can be seen from Figure 5, LW107 had 603 h lost due to shield issues which is almost double the 314 h lost in LW108. While the aging duty of the LW107 shields likely impacted on the lost time in LW107, this effect potentially would have been equalised by the lost time due to the commissioning of the new shields in LW108 and the various teething issues involved. The large amount of time lost due to shield issues in LW107 suggests that the shields were being overloaded due to operating outside of their capacity.

Shield effectiveness determined from LVA data

If a shield is constantly operated in yield it is reasonable to accept that the shield support capacity is inadequate for the working conditions. As such, in order to determine the effectiveness of the shields, and to determine if shields with a capacity as large as 1750 tonnes were necessary, the amount of time the shields were operating in yield should be assessed. In this case, insufficient data was available to calculate total time spent in yield percentage values and, subsequently, the percentage of time that the shields spent operating at or above the yield pressure was calculated instead.

The LVA data was also used to determine the percentage of time that the shields were operating under 250 b. As already stated, areas where the leg pressure values are less than 250 b is indicative of the presence of cavities. As such, by determining the percentage of time the shields spent operating under this pressure, the percentage of time that cavities were encountered for the panel in question is effectively being determined. A summary of the results can be seen in Figure 6.

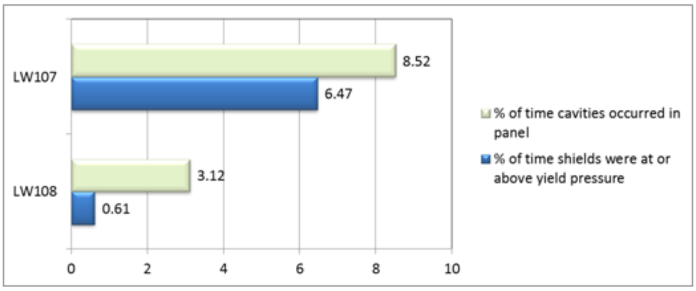

Figure 6 - Shield effectiveness determined from LVA data

The results of the analysis show that the shields in LW108 spent an insignificant amount of time operating at or above the yield pressure value while the LW107 shields had a significantly higher result. Similarly, the amount of time that the shields in LW107 spent operating under 250 b was significantly higher than that experienced by the LW108 shields. Further analysis of shield pressures at different stages in the panel showed the following:

- The LW107 shields directly adjacent to cavity zones consistently went into yield; and
- Even around large cavity zones, the LW108 shields did not go into yield.

These trends can be seen in Figure 7 where the leg pressures have been plotted against the shield numbers.

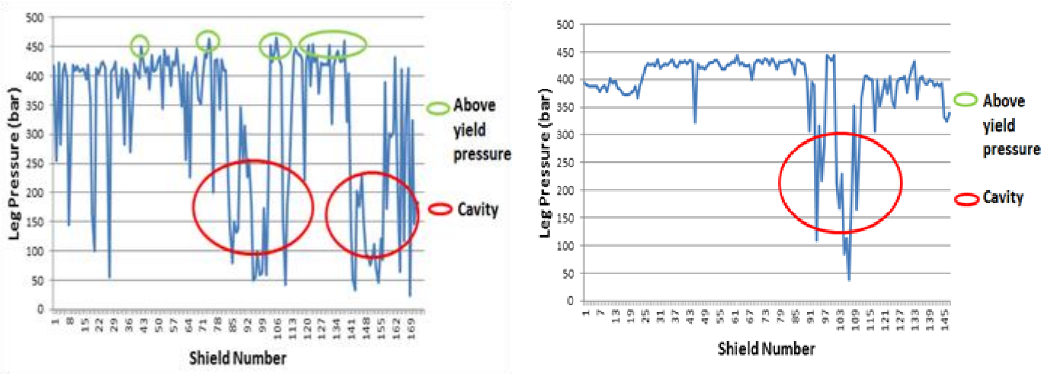

Figure 7 - LW107 (left) and LW108 (right) shield performances around cavity zones

Figure 7 shows that LW107 had constant fluctuations in leg pressure values with several shields operating at or above the yield pressure especially around cavity zones, while the LW108 leg pressures remained relatively constant across the panel, excluding the cavity zones. It also shows that even when increased loading occurred on shields directly adjacent to cavity zones, the leg pressures in LW108 remained well below the yield pressure value. These results indicate that the shields in LW108 were more effective in terms of strata control than LW107 and, similarly, had shield capacities that were more suited to the conditions.

Shield suitability to mining conditions

In order to assess the suitability of the shields for the mining conditions, the total amount of time that the shields spent in yield can be utilised. It should be reiterated that the percentage values previously calculated give the percentage of time the shields operated at or above the yield pressure and not the actual total time the shields spent operating in yield. The actual time the shields spent in yield should include not only the time spent above the yield pressure, but also the time spent in yield as the leg pressure was released until the reset pressure was reached.

Due to data being unavailable with the depth of detail required for the calculation, the actual total time the shields spent in yield could not be determined. However, as this value would be significantly higher than that calculated for the time the shields spent above the yield pressure, the previously calculated percentage values can still be used to determine if the shields were suitable for the mining conditions.

Based on an acceptable yield percentage value of 5%, it can be said that the 980 t shields in LW107 were not suited for the mining conditions. As the percentage of time that the shields spent operating at or above the yield pressure was calculated to be 6.5%, the actual total percentage of time spent in yield would have been significantly higher, hence indicating that the shields were working outside of their capacity. This finding is supported by the large amount of lost production time in LW107, calculated as 148 h, due to face cavities.

Similarly, as the percentage value for the time the shields spent operating at or above the yield pressure for LW108 was calculated to be 0.6%, the actual total percentage of time spent in yield would have been significantly higher. Given the low calculated percentage value, however, it is feasible to say that the shields in LW108 were more than adequate for the mining conditions. This result is in accordance with the low number of lost production hours, calculated as 20 h, due to face cavities in the panel. It is therefore feasible to assume that in future panels of increased depths of over 500 m, the 1750 t shields will have an appropriate capacity, provided that the geotechnical environment will be similar to that experienced in LW 108.

CONCLUSIONS

Moranbah North Mine has a challenging geotechnical environment that historically resulted in cavity formation on the longwall face and unplanned downtimes with a subsequent reduction in productivity. Due to the equally complex geology of the future panels at increased depths of cover, the previous roof support issues gave rise to concerns about roof stability in future panels. It was determined that 1 750 t shields would be required in future panels instead of the previous 980 t shields to combat the various strata issues. As shields of this capacity did not already exist, the shields had to be custom built and still currently remain the highest capacity shields in the world.

Overall, taking into account the results of all aspects of the analysis, it is feasible to say that the 1 750 t shields were more than effective in terms of strata control and the support capacity will be well suited to the mining conditions that will be experienced at greater depths.

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