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A deformation monitoring plan for extraction level drives at Ridgeway Deeps block cave mine

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Abstract

Understanding the deformation of the rock mass surrounding extraction drives in a block cave mine is important for designing and implementing ground support, tracking the remaining ground support capacity, and for validating numerical models. This paper describes the rock mass response on the extraction level during the undercutting and early production stages of the Newcrest Mining Limited's Ridgeway Deeps block cave mine. A summary of the planned instrumentation and monitoring program which is currently being implemented is also included. The paper also presents some of the deformation data collected to date and highlights issues identified and remedies implemented relating to both the quality of the data and data collection practices.

1 Introduction

This paper describes a deformation monitoring plan currently being implemented for the extraction level at the Ridgeway Deeps block cave mine. This deformation monitoring plan has been implemented for the following reasons. Firstly, to provide a safety monitoring program for trigger action response plans. Secondly, to quantify the performance of the installed reinforcement and support, to allow improved designs for future block caving operations within Newcrest. Thirdly, to quantify rock mass failure mechanisms and dilation, which impact on several aspects of the extraction level drive stability.

The paper presents deformation data collected in the early stages of undercutting where a relation between the depth of damage and drive closure was measured. The paper also highlights some of the issues identified and remedial action taken relating to both the quality of the data and the data collection processes experienced to date.

The data collected from the deformation monitoring plans on the undercut and extraction levels will be used to investigate the factors controlling rock mass dilation around extraction drives in high stress mining environments.

2 Background

The Ridgeway Deeps block cave is a new operation developed within Newcrest Mining Limited's Cadia Valley Operations, located approximately 20 km South West of the city of Orange in the NSW central west. The block cave forms the continuation of the existing Ridgeway sublevel cave (SLC) operation that has been actively mined since 2000. The sublevel cave commenced at a depth of 570 m or 5330 RL (surface elevation is approximately 5900 RL) and workings presently extend to a depth of 890 m or 5010 RL. The block cave extraction level is located directly below the SLC at a depth of around 1,100 m or 4786 RL and is designed to cave the orebody from 4786 RL to 5010 RL.

The block cave incorporates an undercut level at 4804 RL with the extraction level located 18 m below at 4786 RL. The extraction level is based on the Offset Herringbone layout and consists of 15 extraction drives (ED1 to ED15) aligned 30 degrees northeast–southwest (relative to mine north). In total 130 drawbells will be established from 250 drawpoints. The undercut level consists of a crinkle-cut layout and will be mined as an advance undercut. The aim of advance undercutting is to create a stress shadow on the extraction level, into which drawbells and drawpoint drives are developed. Figure 1 displays a plan view schematic of the extraction level, with the undercut geometry superimposed.

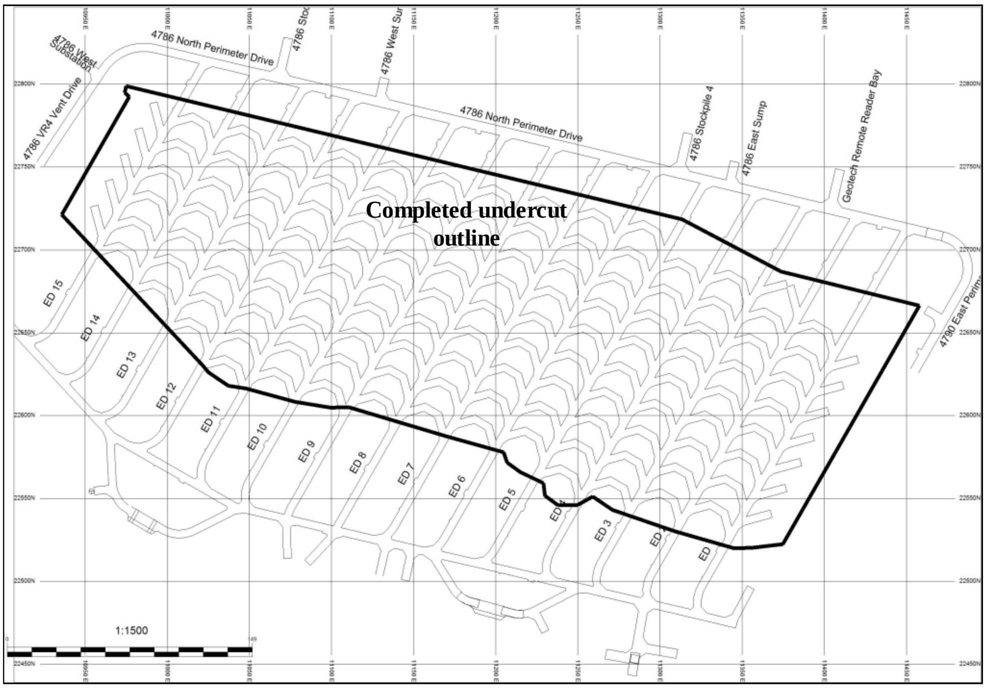

Figure 1 Layout of the Ridgeway Deeps extraction level

2.1 Rock mass characteristics

The Ridgeway Deeps block cave is hosted by three rock types (Lett, 2009). These include Cadia Valley Monzonite, Forrest Reef Volcaniclastics and Weemalla Sediments. Figure 2 displays the geology and major structures associated with the extraction level. Table 1 provides an overview of geotechnical parameters for each rock type.

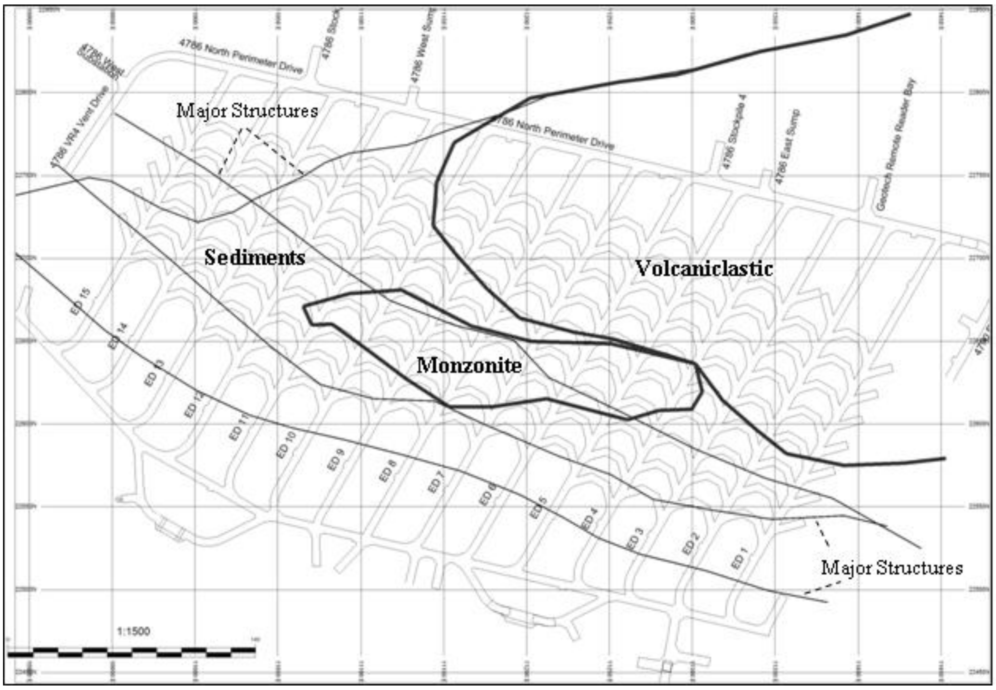

Figure 2 Geology of the Ridgeway Deeps undercut and extraction levels (after Lett, 2009)

Table 1 Rock type characteristics at Ridgeway Deeps (after Lett, 2009)

Rock Type	Characteristics
Monzonite	• UCS: 93–155 MPa (median: 121 MPa) [a,b] • Young's Modulus: 65–69 (median: 67 GPa) • Q': 12–25 (median: 22) [a] • RMR^{L90}: 49–61 (median: 53) [a] • 2 joint sets
Volcaniclastics	• UCS : 87–150 MPa (median: 116 MPa) [a,b] • Young's Modulus: 62–72 (median: 68 GPa) • Q': 5–17 (median: 9) [a] • RMR^{L90}: 53–67 (median: 61) [a] • 2–3 joints sets • Up to 5 mm infill on discontinuities
Sediments	• UCS: 88–144 MPa (median: 99 MPa)[a,b] • Young's Modulus: 63–79 (median: 70 GPa) • Q': 1–8 (median: 4)[a] • RMR^{L90}: 45–62 (median: 52)[a] • 3–4 joint sets • Up to 2 mm infill on discontinuities

[a] Upper and lower quartile values presented

[b] USC tests performed on 60–63 mm diameters core specimens.

2.2 In situ stress environment

Table 2 details the estimated in situ pre-mining principal stresses. The magnitude of the pre-mining principal stresses and stress gradients is based on CSIRO HI Cell measurements. For the purpose of numerical analysis, the direction and orientation of the major principal stress was calibrated to the spatial distribution of mining induced seismicity and observed drive damage, using the procedure described in Wiles (2007).

Table 2 Pre-mining stress environment at a depth of 1,100 m (4786 RL)

Principal Stress	Magnitude (Dip/Dip Direction)*
σ_1	65 MPa (5°/240°)
σ_2	47 MPa (68°/138°)
σ_3	32 MPa (22°/332°)

* Dip Direction is defined relative to mine grid, which is oriented at 32 degrees to AGM Grid North.

The measured vertical stress at a depth of 1,100 m was higher than expected based on theoretical calculations using an average rock density of 2.85 t/m^3. Discing of core was noted at the measurement sites.

3 Stages of deformation

The key aim of deformation monitoring is to quantify the spatial and temporal distribution of deformation parameters influencing the design of extraction level ground support and reinforcement. These parameters include:

- the depth of stress induced damage in the excavation drive sidewalls and back

- excavation closure in the vertical and horizontal directions resulting from rock mass damage, dilation, and large scale changes to the mining induced strain field
- the strain fields induced in the rock mass near the excavation boundary during development of the extraction drives, undercutting and propagation of the cave.

MAP3D has been used at the mine site to correlate mining induced stress changes (from elastic modelling) with various levels of drive convergence and observed blast hole damage (Capes, 2009). These correlations are being used to assist in mine production sequencing. Numerical forward estimates of the deformation parameters were computed using Abaqus and FLAC3D. Based on these estimates, significant inelastic deformations are expected to occur at the following stages of the block cave development:

- Initial drive formation: Deformations in the sidewalls and back have been measured near the face of newly developed extraction drives.
- Undercutting: Due to the dip and dip direction of the major pre-mining principal stress, significant deformations have been measured on the northern side of the extraction level as the undercut hydraulic radius is increased.
- Cave propagation: Numerical models indicate that inelastic deformations on the perimeter of the extraction level increase as the cave propagates towards the SLC.
- Steady state production: during steady-state production from the block cave, changes continue to occur in the rock mass, as damage accumulates due to fracture coalescence.

4 Formulation of the extraction level deformation monitoring plan

4.1 Instruments

Quantifying the magnitude of inelastic deformations experienced in an overstressed rock mass is critical in selecting appropriate ground support (Kaiser et al., 2000). In order to measure the parameters that quantify deformation and surface convergence associated with the various stages of caving, a number of instruments have been chosen. These instruments and the deformation parameters they measure are detailed in Table 3.

Table 3 Deformation instrumentation and parameters used in the extraction level (Earl, 2009)

Instrument	Deformation Parameter
200 mm convergence pins	Wall, shoulder, and back convergence based on 200 mm depth of anchorage.
4 m RWE chains	Rock mass depth of damage in walls at 0–1 m, 1–2 m, 2–4 m intervals.
6 m RWE chains	Rock mass depth of damage in walls at 0–1 m, 1–2 m, 2–4 m, 4–6 m intervals.
6 m SMART extensometers	Rock mass depth of damage in walls to 6 m at 1 m intervals.
6 m SMART cables	Rock mass depth of damage in backs to 6 m at 1 m intervals.
21 m SMART extensometers	Rock mass depth of damage in major apex pillar to 21 m at varying intervals (6 node points in total).
6 m observation holes	Calibration of depth of failure for RWEs, SMART cables, and SMART extensometers.
3DM photogrammetry	Surface convergence of whole drive cross sections in selected areas.

4.2 Installation criteria for instruments

The placement of the instruments in the extraction level has been determined for the following reasons. Firstly, the deformations of the rock mass can be accurately measured at the appropriate resolution, secondly, protection against damage from mining activities and thirdly, ease of installation.

The 6 m SMART cables and 21 m SMART extensometers located in the drive backs are placed as close as possible to the centre of the drives where the maximum drive closure is expected. Convergence pins that measure drive back convergence are installed in the centre of the drive backs although this is not always practical as in places numerous service lines such as mine air and water, electrical cables and catenaries are placed in the drive backs to remove them from proximity to mining activities.

Wall extensometers (6 m SMART extensometers as supplied by Mine Design Technologies Inc., Canada and 4 and 6 m RWE chains as supplied by Top Rock Solutions, Australia) and wall convergence pins are placed between 1.5 and 1.7 m from the floor. Convergence pins, where possible, are placed in depressed sections of the walls to minimise the risk of being struck by mining equipment. In high exposure areas, thick conveyor flaps are now being used to cover these wall installations in an attempt to offer some protection from loaders and other mining equipment as well as from fly rock due to blasting in close proximity. The flaps are simply bolted onto the walls using threaded eye bolts. The eye bolts and conveyor flaps can be easily removed and re-installed when the instruments need to be read.

The 200 mm convergence pins are installed so that the thread of the bolt is fully embodied into the walls. The pins are fully grouted using a chemical resin to ensure a complete 200 mm deep anchorage.

All extensometer type instruments are installed so that the ends of the instruments are located as close as possible to the surface of the excavation without the instrument being exposed. The tag readers and cabling are run from the instrument to the observation hole where they are tucked away to avoid being contacted by mining equipment.

Figure 3 details the location of a selection of these instruments on the northern side of the extraction level in and around ED11.

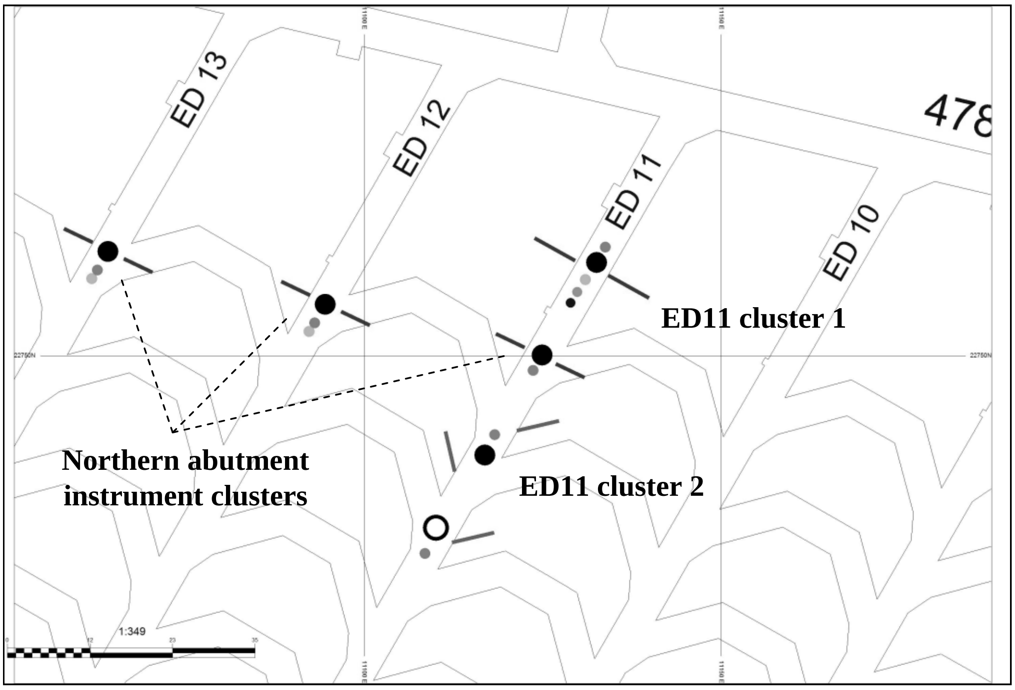

Figure 3 Instrumentation locations in and around ED11 northern side

As seen in Figure 3, the northern abutment instrument clusters in ED11, 12, and 13 are sacrificial and are intended to measure the deformation and surface convergence associated with the advance undercut. They consist of 6 m SMART cables in the backs and 4 m RWE chains in the walls; 200 mm convergence pins are located in the walls, shoulders, and backs.

Instrument cluster 1 located in ED11 (Figure 3) measures the deformation and convergence associated with the abutment stresses expected as the cave is propagated towards the existing SLC. This cluster is replicated at four locations on the northern side of the extraction level as well as four locations on the southern side. These instruments consist of 6 m SMART cables in the backs accompanied with 6 m extensometers in the walls. 200 mm convergence pins here are placed in the backs, shoulders, and sidewalls.

In four selected extraction drives (ED3, 7, 11, and 14) numerous instrument clusters (18 in total) will be installed along the extent of the drives to measure the variations in deformation along the length of these drive from the edges of the undercut footprint to the centre of the drives. Instrument cluster 2 displayed in Figure 3 is typical of these clusters. The clusters incorporate 6 m SMART cables in the backs accompanied with 6 m extensometers in the walls. In selected locations 21 m long extensometers are installed into the backs which penetrate the major apex pillars. These instruments are aimed at determining the extent of deformation in these pillars as the cave is propagated. A schematic of a typical instrumentation cluster is displayed in Figure 4.

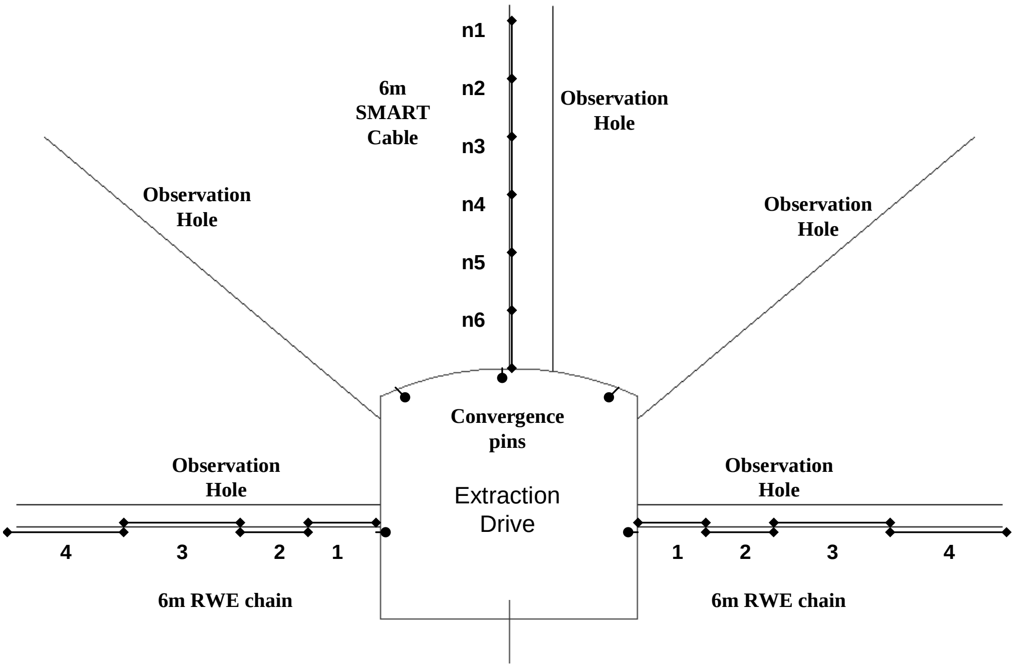

Figure 4 Schematic of a typical instrumentation cluster (after Lowther and Capes, 2009)

5 Deformations measured during undercutting and early cave propagation

In order to track the progression of deformation in the extraction level as the undercut is advanced and as the cave is propagated to breakthrough, the extraction level is fully inspected once per month and a monthly damage map is generated. The location and severity of the damage is recorded in Minecad software (GijimaAST Mining Ltd) and used to produce a monthly summary of the damage as displayed in Figure 5.

The deformation state is visually assessed when the monthly 4786 extraction level damage mapping occurs. Damage is categorised into three levels, L1, L2 and L3. These levels define structural changes in the ground support and reinforcement systems, associated with mining induced deformations:

- L1 is the onset of observable damage in the fibrecrete.
- L2 is when the fibrecrete damage intensifies and when the onset of deformation in the rock bolts begins.
- L3 is where the previously installed ground support is deforming and may require rehabilitation with additional support.

This visual damage assessment criterion is detailed in Table 4.

Table 4 Visual damage assessment criterion

Level of Damage	Visual Characteristics
L1 damage	Sidewall convergence: 10–40 mm Onset of fibrecrete cracking No connectivity between cracks Bolt plates do not display signs of loading Ground water seeping from cracks
L2 damage	Sidewall convergence: 40–80 mm Bolt plates may display localised signs of loading Spalling of fibrecrete Mesh holds back majority of spalling fibrecrete Ground water seeping from cracks
L3 damage	Sidewall convergence: 80–110 mm Cracks coalesce Greater than four adjacent bolt plates displaying plate loading Ground water seeping from cracks

To date, the extraction drives have undergone several stages of mining induced inelastic deformation which include:

- Deformation as the extraction drives are developed through virgin rock. At Ridgeway the initial inelastic ground reaction to newly mined excavations is approximately 4 mm of vertical and horizontal closure as the face of a development heading is advanced.
- Deformation on the extraction level as the undercut is advanced. The most significant damage observed to date (L2 and L3 damage) has been measured along the northern ends of extraction drives 1 to 11 as shown in Figure 5. The location of damage agrees with elastic modelling predictions based on the estimated pre-mining stress field. Less significant deformation (L1 damage) has been measured along the southern ends of extraction drives 1 to 6 and also along ED1. A detailed discussion of the measured deformation is presented in the following sections.

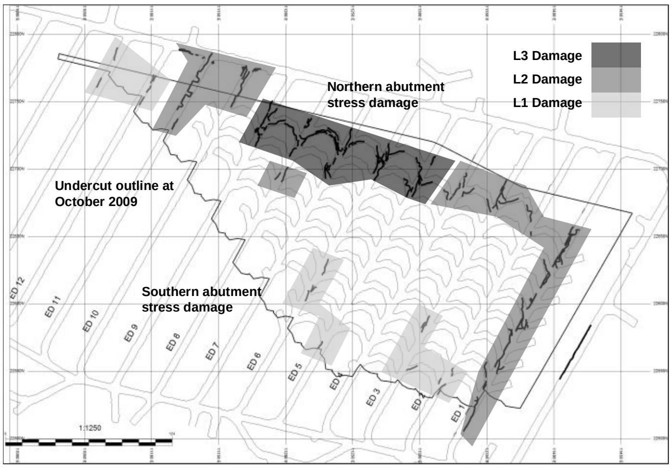

Figure 5 Location of damage on the extraction level as at October 2009

5.1 Northern abutment convergence levels

The highest levels of deformation (L3, Figure 5) have been measured on the northern section of extraction drives 5 to 9. Data compiled from convergence pins located at chainage 50 m, near the area of maximum observed deformation is shown in Figure 6. These pins were installed in numerous locations about the northern end of each extraction drive specifically to measure the extent of this drive closure as the undercut advanced. Figure 7 shows the measurement site with respect to the advancing undercut.

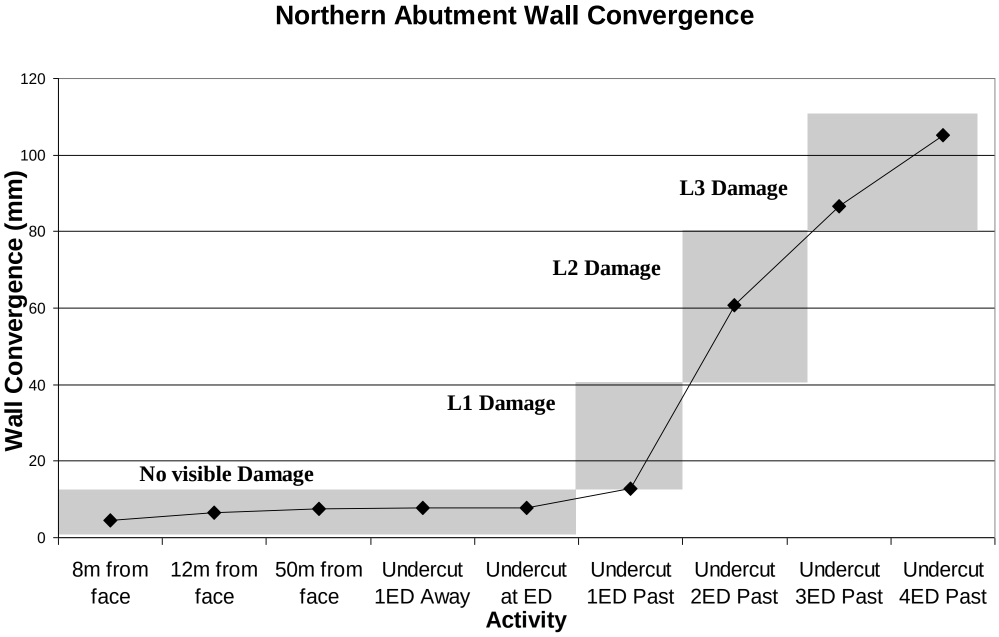

Figure 6 Northern abutment drive closure (at chainage 50 m) with reference to undercut position

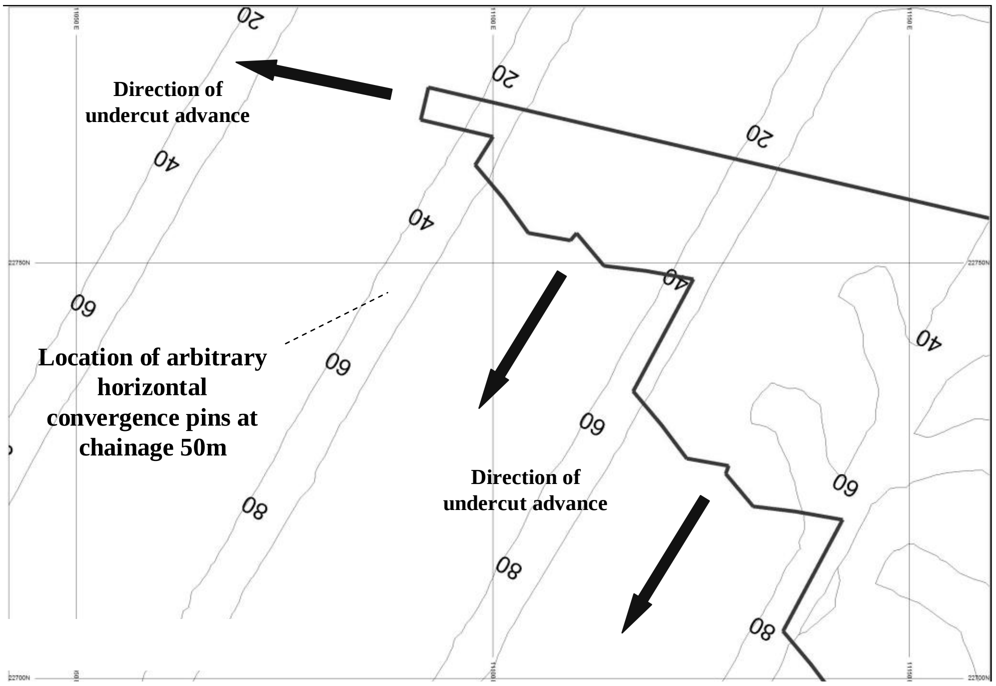

Figure 7 Point of measurement in an arbitrary extraction drive at chainage 50 m

The data indicates that as the extraction drives are developed, approximately 4 mm of sidewall convergence occurs. When the undercut passes directly over the extraction drives the sidewall convergence increases to around 10 to 20 mm and the onset of L1 damage occurs. As the undercut is advanced by 30, 60 and 90 m past the point of measurement, the surface convergence continues to increase and the observable damage evolves from L1 to L2 damage and eventually to L3 damage. Once the undercut has advanced to beyond 120 m past the point of measurement, the development of the drawpoint break-offs commences and the pins are destroyed. Additional instruments are to be installed to ensure all stages of deformation are measured.

5.2 Observed relation between extensometer and convergence measurements

The purpose of establishing a relation between drive closure and depth of damage into the surrounding rock mass is to enable estimates of depth of damage to be made from measurements recorded by the 200 mm convergence pins. This is because the convergence pins are relatively inexpensive and easy to install when compared to extensometer instruments.

This section details a case study of the observed relation between the deformations measured within the rock mass surrounding an extraction drive and the resulting drive closure with data sourced from instrument cluster 1 in ED11 (Figure 3). This cluster contains 6 m RWE chains in each wall, a 6 m smart cable in the back, and 200 mm convergence pins located in the walls and back. Figures 8 and 9 display the extensometer data from both the east and west walls with respect to the measured horizontal drive closure.

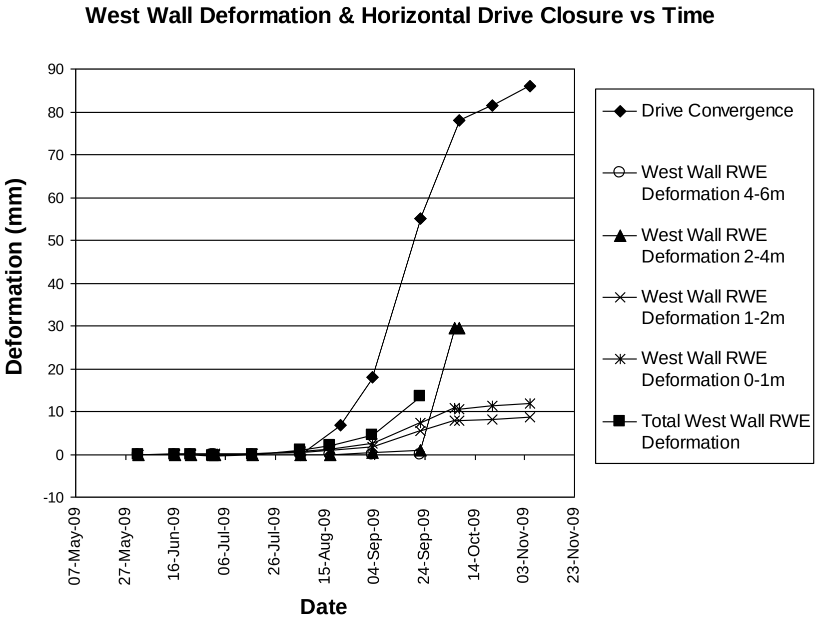

Figure 8 Drive closure and rock mass depth of damage in the west wall of ED11 instrument cluster 1

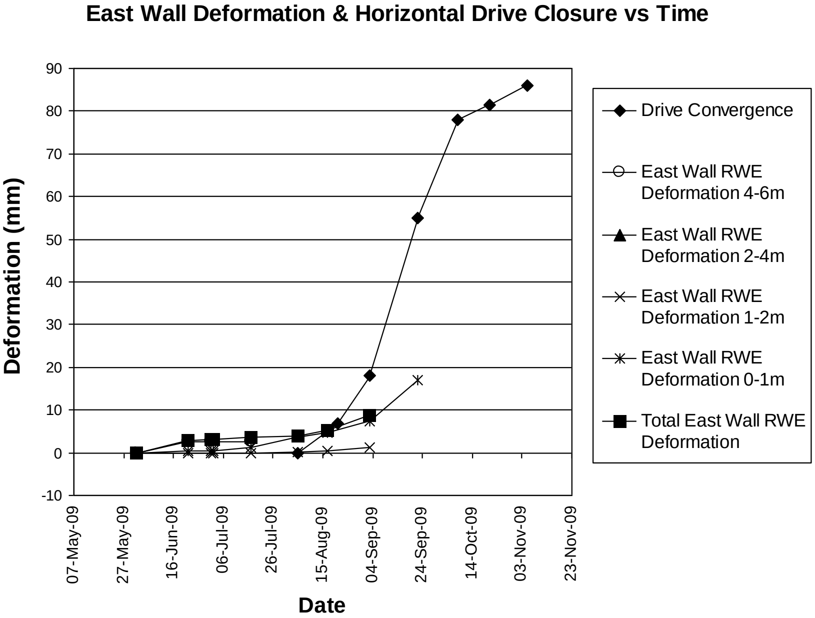

Figure 9 Surface convergence coupled with rock mass depth of damage in the east wall of the ED11 cluster

The total horizontal drive closure at the ED11 instrumentation site is 86 mm. Closure is defined as the relative change in distance between the two wall pins, and has a positive inwards sign convention. Since various extensometers from both walls became inoperable during the drive closure, points in time had to be chosen where adequate data was available to allow for comparisons to be made between the deformations occurring within each wall.

From Figure 8, on 23 September 2009 the rock mass in the west wall had deformed by 14 mm. The corresponding drive closure at this point in time was measured to be 55 mm indicating that the west wall RWE chain accounts for approximately 25% of the total rock mass deformation as measured by the convergence pins. At 3 September 2009 this ratio was 4 mm compared to 18 mm or 22%.

From Figure 9 the RWE instruments measuring deformation from 2 to 4 m into the rock mass became inoperable prior to any data being recorded hence the total deformation of the rock mass in the east wall cannot be accurately determined. Approximately 1 mm of elongation was registered by the RWE instrument measuring deformation from 1 to 2 m into the rock mass up to 3 September 2009. Based on the observed rock mass response at the mine it is assumed that insignificant deformation was recorded in the RWE instrument located from 2 to 4 m into the rock mass. This results in the total deformation in the east wall rock mass to be 9 mm on 3 September 2009. The corresponding drive closure at this point in time was 18 mm indicating that the east wall RWE chain accounts for approximately 50% of the total rock mass deformation as measured by the convergence pins.

In the case study presented the failure of the RWE instruments did not allow for a correlation to be made between drive closure and the total rock mass deformation past 3 September 2009. From the data acquired up to 3 September 2009 the RWE chains accounted for approximately 72% (50 and 22%) of the total drive closure. This implies that a discrepancy of approximately 28% exists between the total rock mass deformation as measured by the RWE chains and the drive closure as measured by the convergence pins. Capes (2009) has demonstrated with a number of examples that the cause of this discrepancy is due to the convergence pins being located at the surface of the excavation while the RWE chains are slightly recessed into the excavation boundary. This may result in the convergence pins registering deformation prior to the RWE units.

Figure 10 displays a graph of the response of the 6 m SMART cable located in the back at the ED11 cluster compared with the surface convergence as measured between the wall pins and the back pin. This data is presented as the deformation registered along the SMART cable from the anchor (toe) of the instrument (node point 1 in Figure 4) to the various node points located at 1 m intervals along the instrument all the way to the collar (node point 6 in Figure 4). This methodology for interpreting SMART cable data is consistent with the method described by Tod and Lausch (2002).

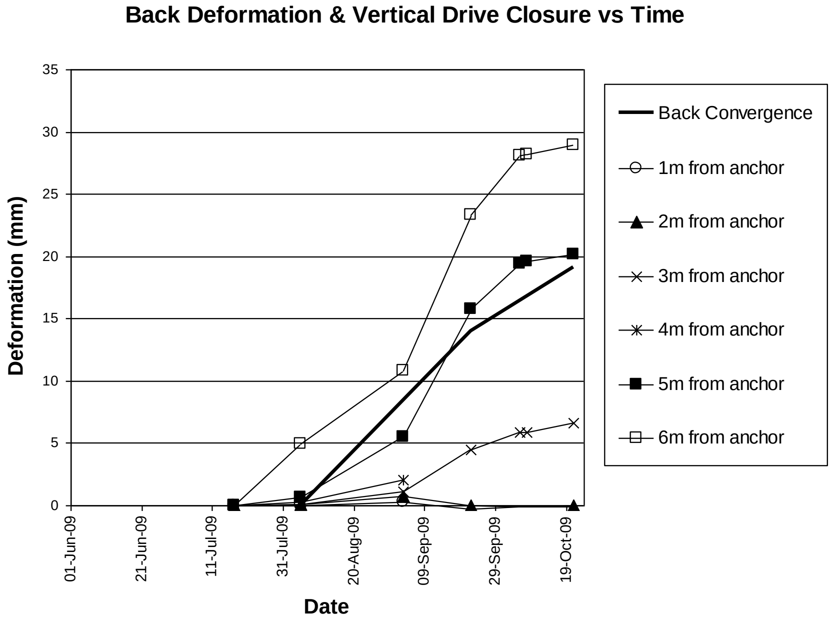

Figure 10 **Surface convergence and total rock mass depth of deformation in the back at the ED11 cluster**

From the data displayed in Figure 10, the maximum deformation in the back occurs in the first metre of the rock mass. This is similar to the response of the walls. The deformation is 9 mm (29–20 mm). The deformation registered in the second and third metre of the rock mass is not able to be presented as the fifth node point in the cable became inoperable after 2 mm of deformation was recorded. From the data presented by the 4th node point it is evident that the deformation between 3 and 4 m into the rock mass is 7 mm (7–0 mm). The maximum observed depth of damage into the back is 4 m.

The convergence pins measuring back convergence registered a closure of 19 mm. This is inconsistent with the total dilation of 29 mm observed in the rock mass by the SMART cable. It can be difficult, however, to accurately determine the extent of vertical drive closure when using the wall pins as reference points. This is because all three convergence pins are moving relative to one another and their initial and final coordinates are unknown (Moosavi and Khazaei, 2003, and Kontogianni and Stiros, 2003). One solution to this problem is to measure closure between the centre of the back and the centre of the floor but this is not practical in the current mining environment. When the concrete floors of the extraction drives have been established it may be possible to install a counter-sunk convergence pin in the centre of the floors to increase the accuracy of these vertical drive closure measurements.

6 Improved wall convergence monitoring techniques

Convergence monitoring in the extraction level is achieved by measuring the change in distance between 200 mm convergence pins using a digital tape extensometer. Whilst this is an accepted method of determining drive closure, the small number of measurement points does not allow an accurate assessment of the full drive surface displacement field. In addition, closure pins provide only relative movements, and do not distinguish between which sections of the walls are moving and which are not. To measure the full surface displacement field, 3DM photogrammetry is planned to be used in conjunction with an array of 200 mm convergence pins. Lett and Emmi (2009) conducted experimentation into adapting Adam-Tech 3DM photogrammetry for use in drive closure analysis.

7 Data collection issues and learnings

7.1 Second pass ground support

To aid in development advance, the Ridgeway Deeps project utilises two passes of ground support in the extraction level. The first pass consists of fibrecrete and bolts. The second pass consists of a layer of mesh and additional fibrecrete. Unfortunately the second pass of ground support has covered some instrumentation installations. In order to avoid this in subsequent installations a strategy has been employed where ground support modification requests have been issued by the geotechnical department to have the complete ground support regimes installed early at planned instrumentation sites prior to the instruments being installed. In addition to this all instrument installations are now accompanied with a sign stating “Geotechnical Instrumentation, Do Not Damage or Spray Fibrecrete”.

7.2 Blast damage

It is advantageous to install the instruments as early as possible so that the total deformation history is recorded. If the instruments are installed after the deformation has commenced then the data cannot be placed into a stress–strain curve with confidence. The problem with installing instruments early in the development cycle is that they are exposed to development and drawbell firings. As previously mentioned thick conveyor flaps are now being used to cover the wall installations in an attempt to offer some protection from loaders and other mining equipment as well as from fly rock due to blasting in close proximity. The flaps are simply bolted onto the walls using threaded eye bolts. The eye bolts and conveyor flaps can be easily removed and re-installed when the instruments are to be read.

7.3 Loader damage

Several instruments have been lost to loader damage as they tram in the extraction drives. In order to minimise the exposure of the exposed parts of the instruments, the instruments, where possible, are placed into existing depressions in the walls. This counter-measure can significantly reduce the likelihood of damage to the instruments.

7.4 RWE limitations

Early RWE installations incorporated the reader cables being encapsulated in grout with the instrument. This encapsulation resulted in the cables having virtually no stretch and hence when axial deformation of the rock mass occurred the cables broke and communication with the instruments was lost. The way to overcome this limitation is to sheath the cables with conduit (Walton, 2009) but this has two disadvantages. Firstly it adds substantially to the installation time and secondly it means that the instrument is inserted with numerous conduit pipes which can compromise the grout to instrument and grout to rock mass bond if the hole diameter is too small. The 6 m SMART extensometers house the cables internally within the instrument and do not have this problem. Subsequently future installations will consist of 6 m SMART extensometers and sheathed RWE chains.

8 Summary

The instrumentation monitoring plan and damage mapping practices used at the Ridgeway Deeps block cave has allowed an understanding of the development of damage in the extraction level. Correlations have been made between the depth of damage into the rock mass surrounding extraction drives and the resulting drive closure. Measurement accuracy and instrument longevity problems have been observed and methods to overcome these limitations have been suggested to improve the quality of data obtained from this deformation monitoring plan.

Future data obtained from this monitoring plan as well as the routine damage mapping will be coupled with detailed rock mass parameters obtained from face mapping, stress states obtained from numerical models, and seismic data obtained from the mine’s microseismic system. This information will be used to develop an understanding of the mechanical response of the rock types present at Cadia Valley Operations to mining induced stress states. An understanding of this rock mass response will aid in the design and installation of ground support as well as predicting the remaining capacity of the installed support as the deformation evolves.

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