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# INSEAM BOREHOLES TO AND BEYOND 2000 M WITH A COMBINATION OF SLIDE AND ROTARY DRILLING

Frank Hungerford<sup>1</sup> and Wayne Green<sup>2</sup>

**ABSTRACT:** Directional drilling has been the established form of in-seam drilling for gas drainage, exploration and water management for the past two decades. Although there has been a desire to achieve longer boreholes to depths similar to that achieved with surface drilling, seam conditions, equipment capacity and drilling methods have limited in-seam drilling depths. Development into a new area of Metropolitan Colliery required boreholes to depths of 2000 m to provide the required gas drainage. This offered an opportunity to use a combination of slide and rotary drilling similar to that used with Surface to Inseam (SIS) drilling to achieve the required depths. This paper describes the drilling techniques used and presents the results of the drilling.

## INTRODUCTION

Metropolitan Colliery is developing in the Bulli seam into a new area which has high gas content; carbon dioxide being the dominant gas. Limited access does not allow the standard gas drainage drilling program to be employed to drain the gas prior to mining. With the proposed gate-roads 2000 m long, the colliery approached VLI to attempt drilling long, in-seam boreholes to 2000 m and beyond to provide drainage coverage. Drilling shorter holes would necessitate a staged and disrupted development to allow progressive drilling and gas drainage.

Directional drilling in coal mining has been developed to a stage where standard practices allow boreholes to 1400 m to be drilled regularly in slide drilling mode with the occasional borehole being drilled to beyond 1700 m. The record depth for inseam boreholes was 1761 m in 2002 in Australia (Valley Longwall 2002). To extend the depth to 2000 m, a combination of directional slide and rotary drilling was planned to be applied from the start. Slide drilling mode involves feeding the Down Hole Motor (DHM) into a borehole with "flip-flopping" orientations to provide directional control while with rotary drilling mode, the drill string is rotated over extended lengths while the desired trajectory and alignment are maintained. This paper presents the results of the successful progress with that drilling.

## DEPTH LIMITATIONS

In achieving a depth of 1005 m with the earliest NQ size configuration, penetration had started surging beyond 60 m so the penetration rate was progressively reduced to prevent stalling of the DHM as borehole depths increased (Hungerford *et al.*, 1988). Eventually surging and the resultant stalling would cause the termination and limit the depth of longholes. A 2-7/8" Accu-drill DHM was offered to the industry in 1992 through Asahi (Walsh and Hungerford, 1993.). This unit had a non-magnetic, high-torque, low-speed 4-5 lobe motor section (Hungerford 1995) which, when fitted with a 1.25° bend and combined with a 96.1 mm diameter Poly Crystalline Drill (PCD) bit, greatly reduced surging (which had been attributed to in-hole friction) and drilling rates improved. In 1993 and 1994, the first two boreholes drilled with this configuration achieved lengths of 1233 m and 1535 m (Walsh and Hungerford 1993). This configuration was established as the standard for in-seam drilling in Australia and eventually the world.

With the higher thrust loading involved, the capacity of in-hole equipment was going to be tested. Analysis of drilling data collected from long-holes with torque/drag models established, showed that the NQ drill rod strength was adequate for the depths achieved to date (Gray 1991), but that borehole depth would eventually be limited due to helical buckling with the current drilling techniques (Gray 1992). Tests of rod strength had proven that the preferred drill rod joint known as CHD being adopted by the industry was the superior rod in strength and ease of handling in jointing (Gray and Daniel 2000). Withdrawal friction and rotation were also thought to be limiting factors from these analyses.

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The severity and number of bends in the initial stages of a borehole influences the rate of drilling. The in-hole friction increases as borehole depth increases (Hungerford *et al.*, 2012). Any attempt at longhole drilling may necessitate limiting bends in the borehole, particularly in the initial stages.

### Surveying

The survey systems were thought to be a limiting factor with the DDM-MECCA initially preferred over the DGS due to signal strength. Previous boreholes drilled to and beyond 1500 m had suffered from signal strength problems when using the DGS. Subsequent development of the Drilling Guidance System (DGS) (McCabe and Hellyer 2013) apparently improved signal strength and transmission but this yet to be proved over the longer lengths.

To enhance the chances of successful signal transmission at depth, relatively new CHD rods were used with the DPI RCS (Rod Communication System – similar to the AMT MECCA) installed.

### Drilling configuration

The DPI equivalent of the non-magnetic 4/5 Accu-Dril DHM was used with a  $1.125^\circ$  bent housing fitted with a 1 mm thick wear pad. A standard Asahi 96.1 mm diameter PCD bit was used which combined for an off-set at the bit (B) in Figure 1 of 6.7 mm. This was equivalent to being fitted with a bent housing of  $1.22^\circ$ . In initial rotation of the DHM, the heel of the bend would be flexed 2.9 mm to fit within the 96.1 mm diameter until the hole diameter was increased by the rotation.

After the first hole, the bit size was increased to 99 mm by moving the outer cutters outward. This reduced the off-set at the bit (B) to 5.3 mm and thus reduced the effective bend to  $1.12^\circ$ . In rotating the DHM, the heel of the bend fits within the 99 mm diameter thus avoiding any flexing of the DHM.



**Figure 1: Deflection of DHM (A) and bit (B) with wear pad**

### RIG CAPACITY

Due to a combination of size limitations in getting equipment into the mine and availability of drill rigs, the initial drill supplied for the project was a modular VLI Series 1000. This drill rig had a thrust capacity of 104.6 kN compared to 140 kN of the track mounted Series 1000.

### Drilling Practice

Longhole drilling had become an established practice with the conventional flip-flopping of DHM bend orientation for directional control. But with the practice of a change in orientation every 6 m, 1200 m long boreholes were relatively common with only the occasional borehole being drilled beyond 1500 m. Several methods had been employed to extend borehole depths. These included:

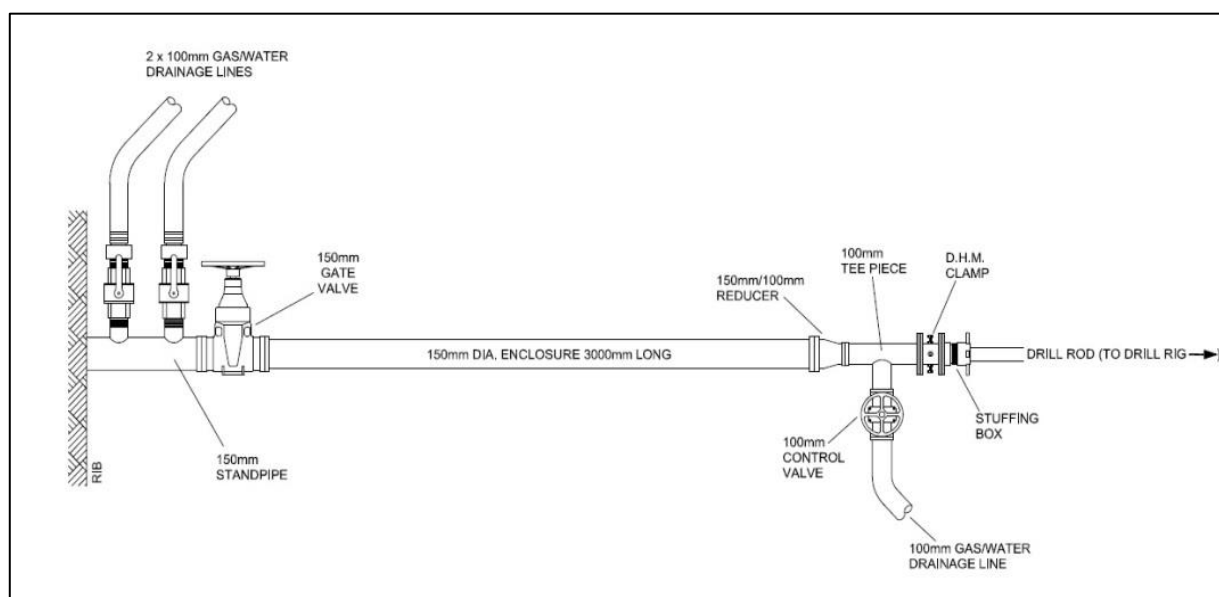
- Reaming sections of the borehole to a larger diameter (Valley Longwall 2002),
- Reducing the bend on the DHM, using an impregnated bit and high speed 1/2 lobe DHM (Kravits *et al.*, 1999).
- Increasing the length drilled on each side of the flip-flop drilling method (Gray 1991), and
- Employing a rotary/slide method of drilling commonly used by SIS drilling and previously in some underground drilling operations (Eade 2002).

Before drilling commenced, the drillers were instructed on the drilling practices required for the project. Most drillers had used rotary slide for short sections of drilling on previous projects so were conversant with the practice. The initial drilling parameters included:

- Slide drilling to establish position and dip within the seam and on alignment/azimuth.

- Slide drilling to maintain lateral borehole curve to remain on line.
- Slide drilling to target the seam roof for seam profile definition.
- Slide drilling to establish each branch.
- 200 litres/min water flow to operate the DHM.
- Rotary drilling whenever possible when comfortably on line.
- Rotary drilling at 30 – 60 rpm to limit damage and wear to the DHM.
- Record usual drilling parameters of thrust and hold-back hydraulic pressures and water idle and drilling pressures.
- Survey at 6 m intervals and also record each 3 m intermediate survey.
- Record main hydraulic pump pressure when rotary drilling.

To manage all returns from the borehole, drilling was to be through a 150 mm standpipe and valve. With high gas flows expected from the boreholes, the rig was set back from the face to allow a 3 m enclosure (Figure 2) for withdrawing the DHM from the hole.



**Figure 2: Standpipe configuration with 3 m enclosure**

### Drilling Conditions

Ultimately, drilling conditions have an influence on the borehole depths achieved. Good intact coal conditions allow for easy directional drilling with DHMs with minimum problems with in-hole collapse and bogging. If any unstable conditions are experienced, ongoing drilling beyond that point will always be suspect with loss of expensive equipment being the main concern. Drilling to extreme depths beyond the 600-700 m over-coring capacity eliminates over-coring as insurance and plans need to be in place to eventually recover the equipment when intersected. The Bulli seam has an average thickness of 3.0 m with no geological structures expected in the area of the proposed drilling.

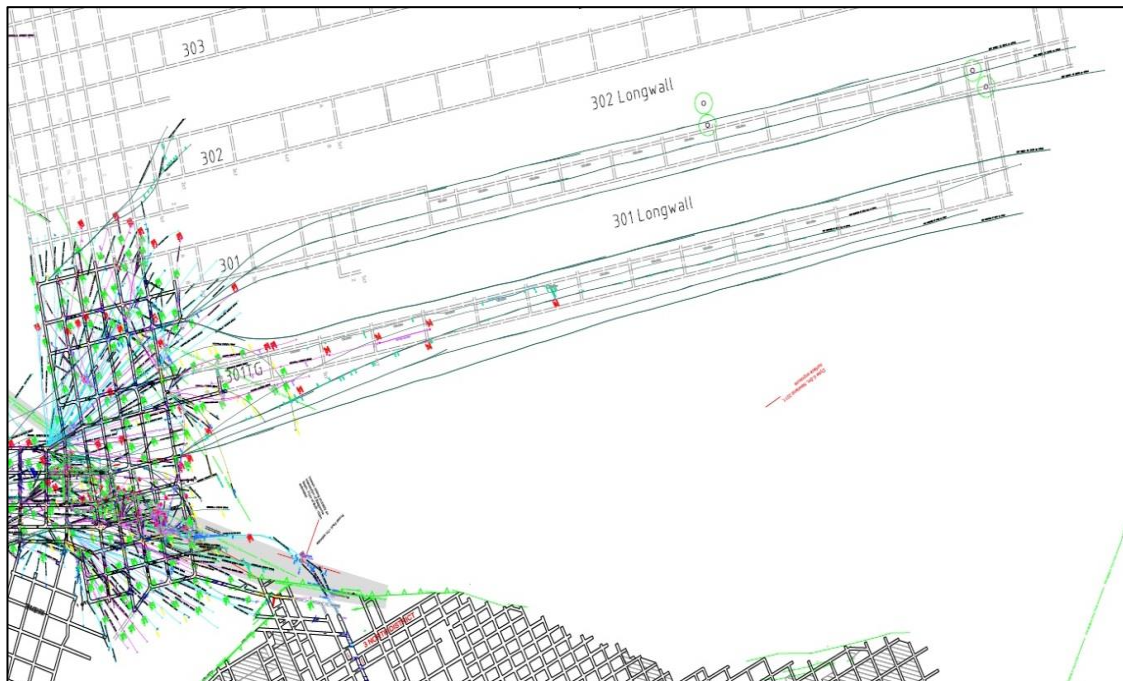
### Drilling Results

Nine boreholes were completed from two drill sites at the time of writing (Table 1). All boreholes were drilled with a combination of slide and rotary drilling. Each borehole had different applications of rotary drilling, off-set entry angle and eventual lateral deviation. That delivered a different depth in each borehole from which slide drilling could no longer continue and drilling was continued with rotary drilling only. The table also indicates the depth to which slide drilling was possible, the lateral deviation and the reason for terminating each borehole.

Figure 3 shows eight of the nine boreholes plotted on the mine plan showing the proposed gate-road development. Drilling conditions were found to be stable with no structures or boggy conditions experienced.

**Table 1: Borehole Data**

| Borehole | Date       | Depth (m) | Slide to (m) | Lat Dev (m) | Terminated |
|----------|------------|-----------|--------------|-------------|------------|
| EX03     | 15/06/2015 | 1716      | 1746         | 116 L       | No signal  |
| EX02     | 19/07/2015 | 1875      | 1851         | 58 L        | Floor      |
| DH01     | 28/07/2015 | 1971      | 1803         | 31 L        | Floor      |
| DH04     | 9/08/2015  | 2001      | 1821         | 129 L       | Roof       |
| DH05     | 31/08/2015 | 2007      | 1653         | 78 R        | To design  |
| DH08     | 23/09/2015 | 2151      | 1743         | 40 L        | No rods    |
| DH09     | 7/10/2015  | 2103      | 1761         | 83 L        | No rods    |
| DH10     | 27/10/2015 | 2007      | 1761         | 121 L       | To design  |
| DH11     | 17/11/2015 | 2016      | 1920         | 166 L       | No rods    |

**Figure 3: Plan of longhole coverage of proposed gate-roads**

Because of limited access, the boreholes could not be designed as straight holes along their target azimuth with a zero lateral deviation. In that, they were designed with lateral curves to provide the required drainage coverage and not set up specifically to create depth records. The lateral deviation is plotted for the boreholes from the two sites (Figures 4 and 5).

With little geological and RL information in the area of the proposed drilling, the initial borehole (EX03) served as an exploration hole with regular roof intersections to define the seam profile. The borehole and seam profile (Figure 6) also shows boreholes crossed and the expected location of cut-troughs in future gate-road development. This borehole was terminated with survey signal problems at 1716 m, which had established a new world record for underground drilling.

Each subsequent borehole increased that record until DH08 established the world record at 2151 m (Table 1). Being the first borehole from the 9 c/t site, regular roof intersections were completed for seam profile definition (Figure 7). The borehole was drilled with a combination of slide and rotary out to 1743 m (Table 1, Figure 8); at which point 45% had been slide mode with 55% rotary. The remainder of the borehole was drilled wasin rotary mode.

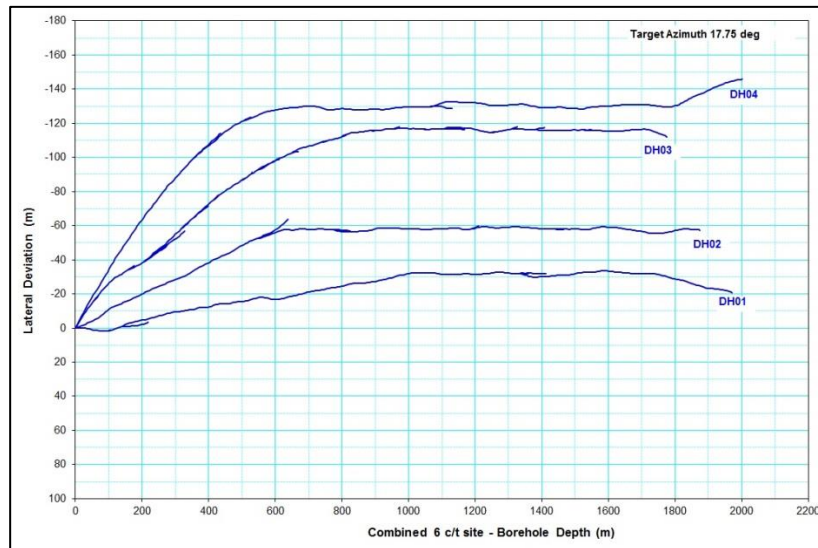


Figure 4: Lateral Deviation of boreholes from 6c/t site

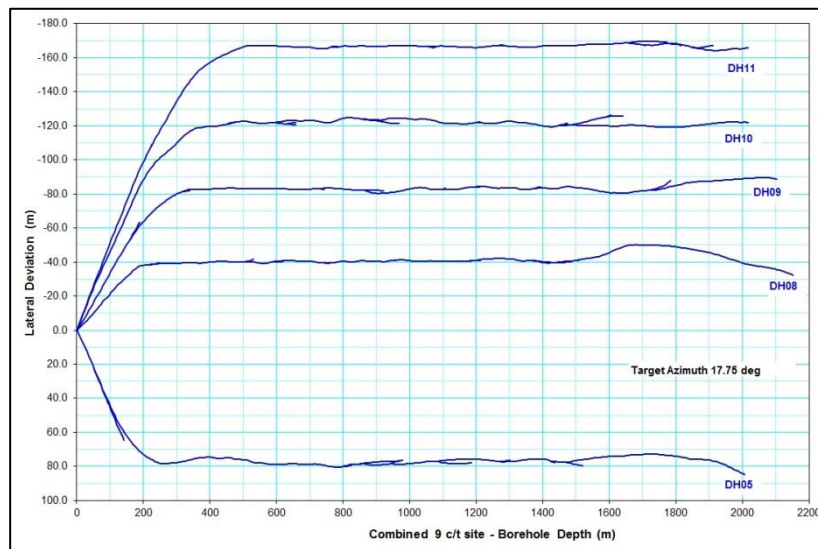


Figure 5: Lateral Deviation of boreholes from 9c/t site

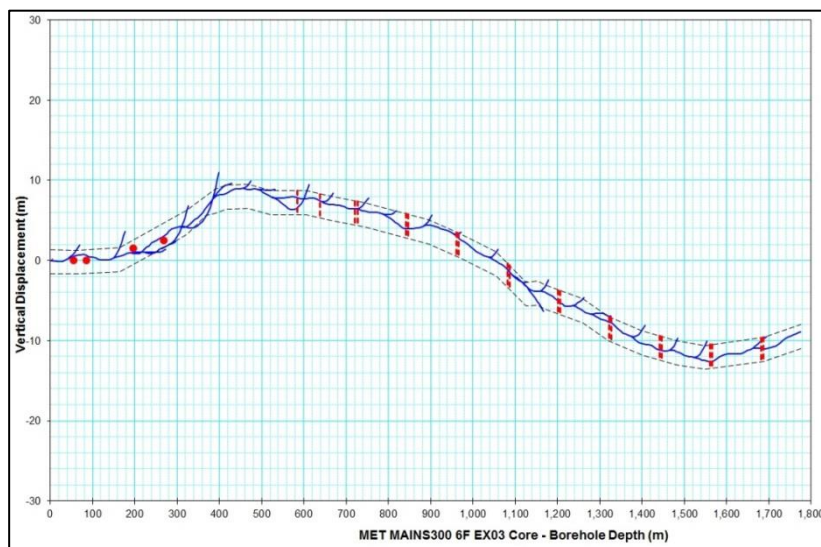


Figure 6: Borehole Profile Metro EX03

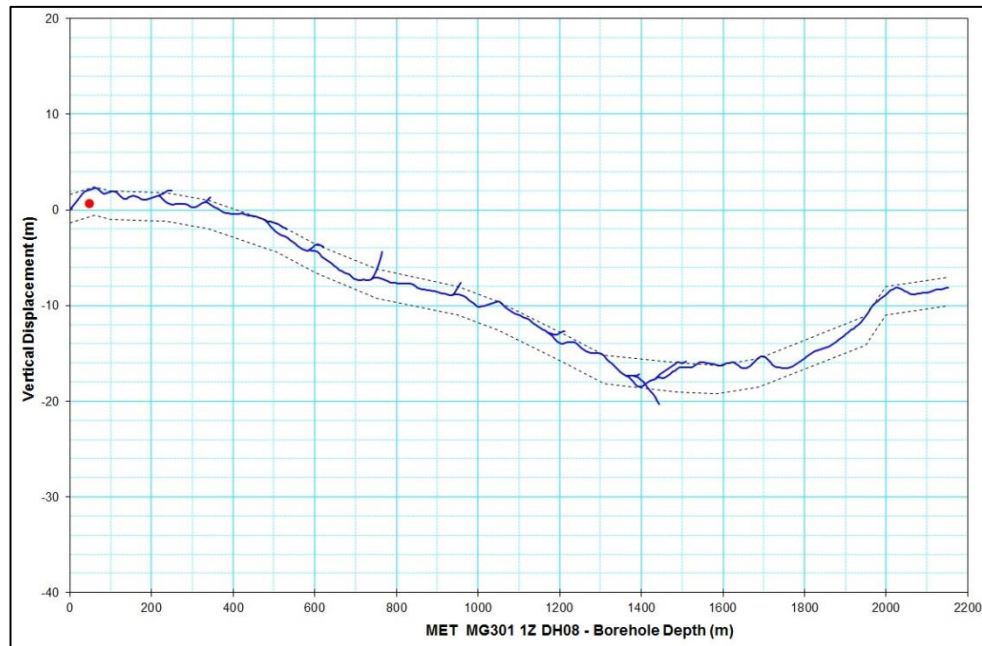


Figure 7: Seam and borehole DH08 profile

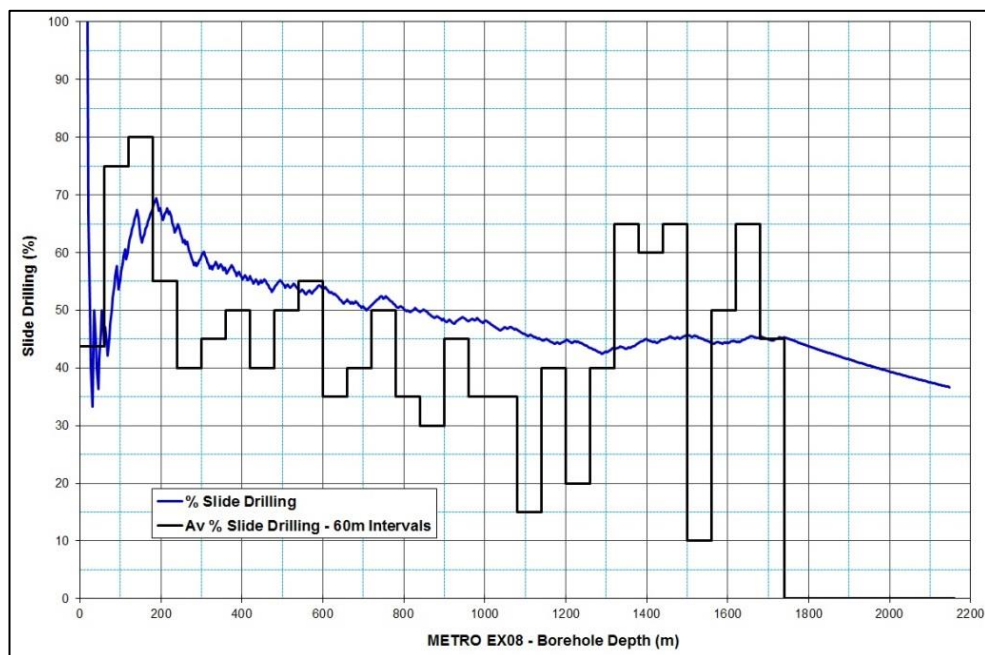


Figure 8: Drilling mode – slide and rotary drilling

The plot of thrust on the drill string for slide drilling (Figure 9) displays the usual trend of increased drilling rate increase with depth, indicating the increased friction effect of curves earlier in the borehole (Hungerford *et al*, 2012). This trend extrapolated to 140 kN thrust would indicate the greater capacity track mounted Series 1000 rig would possibly have managed slide mode drilling to 1900 m in this borehole.

In rotary drilling mode, in-hole friction is greatly reduced (Figure 9) and only starts to increase gradually from the 1400 m depth.

This reduction in friction also provided consistent feed at the bit compared to the surging feed experienced in slide mode. With consistent loading on the bit and DHM, drilling rates are more consistent over depth compared to the rapid reduction in the slide drilling rate (Figure 10) to avoid stalling the DHM.

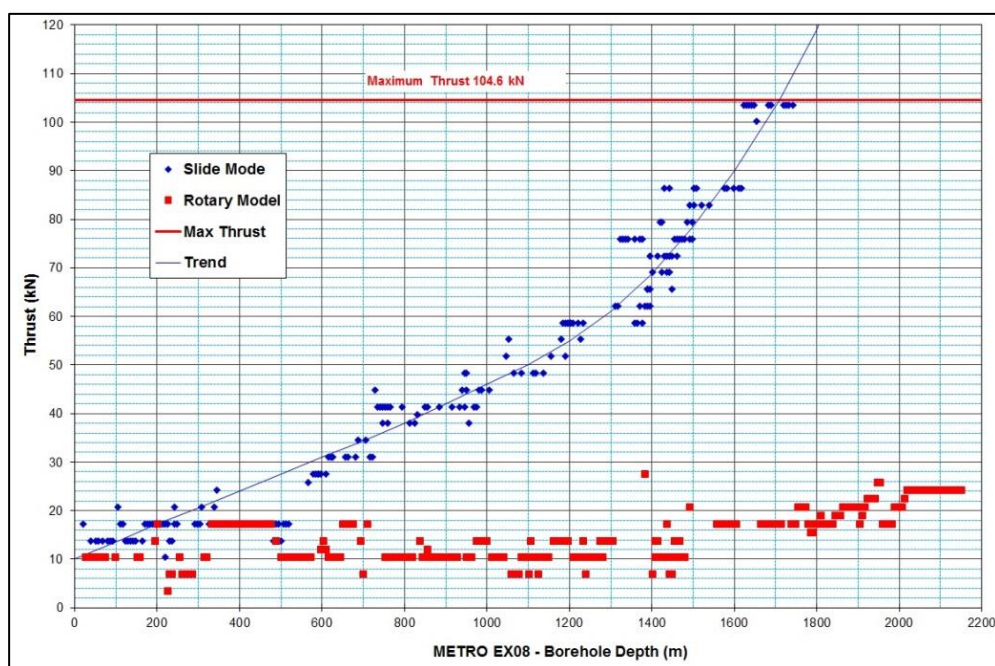


Figure 9: Thrust loading in slide and rotary drilling modes

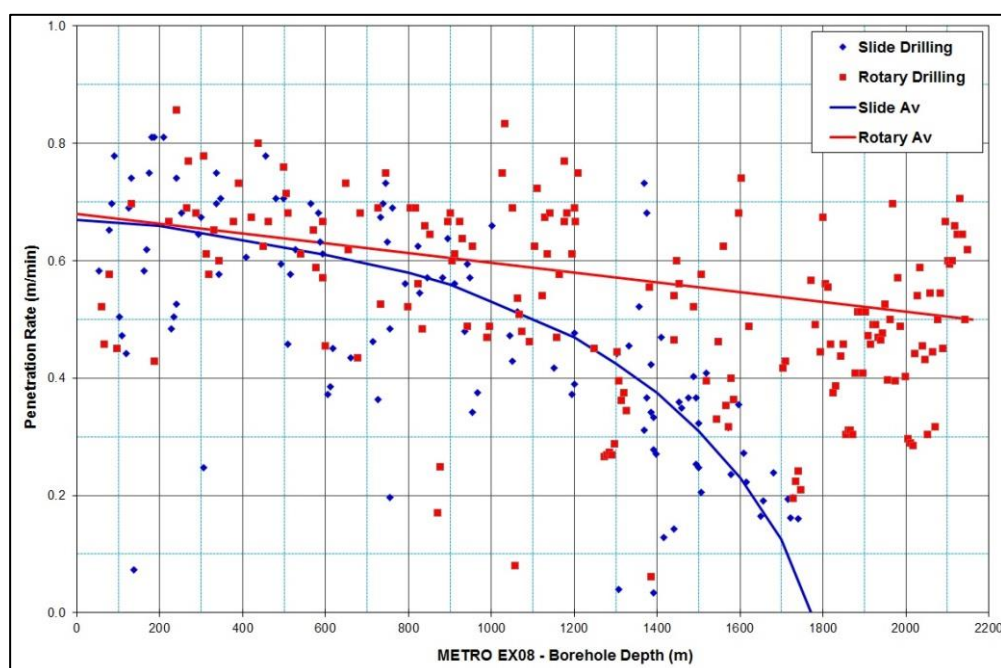


Figure 10: Drilling rate – slide and rotary drilling

Water pressure was a concern before drilling commenced with the increase in idle pressure with drill string length likely to approach the maximum available from the pump. The drilling was commenced using 200 litres/min water flow to assess the progressive increase with depth and identify any potential problems by extrapolating that trend to beyond 2000 m. From Figure 11, the idle pressure increased from 1.5 MPa (at the start) at a rate of 0.15 MPa/100 m. The drilling pressure decreased gradually over the depth of the borehole as drilling rates decreased.

Although the idle pressure was more than 2 MPa below the maximum available pump pressure at depths beyond 2000 m, problems were encountered when starting the DHM. The pressure spike (on starting) occasionally took the water pressure above 7 MPa and stalled the pump before the DHM started. Lower water flow (generating lower pressure) was usually required to start the pump for drilling before the flow was increased back to 200 litres/min.

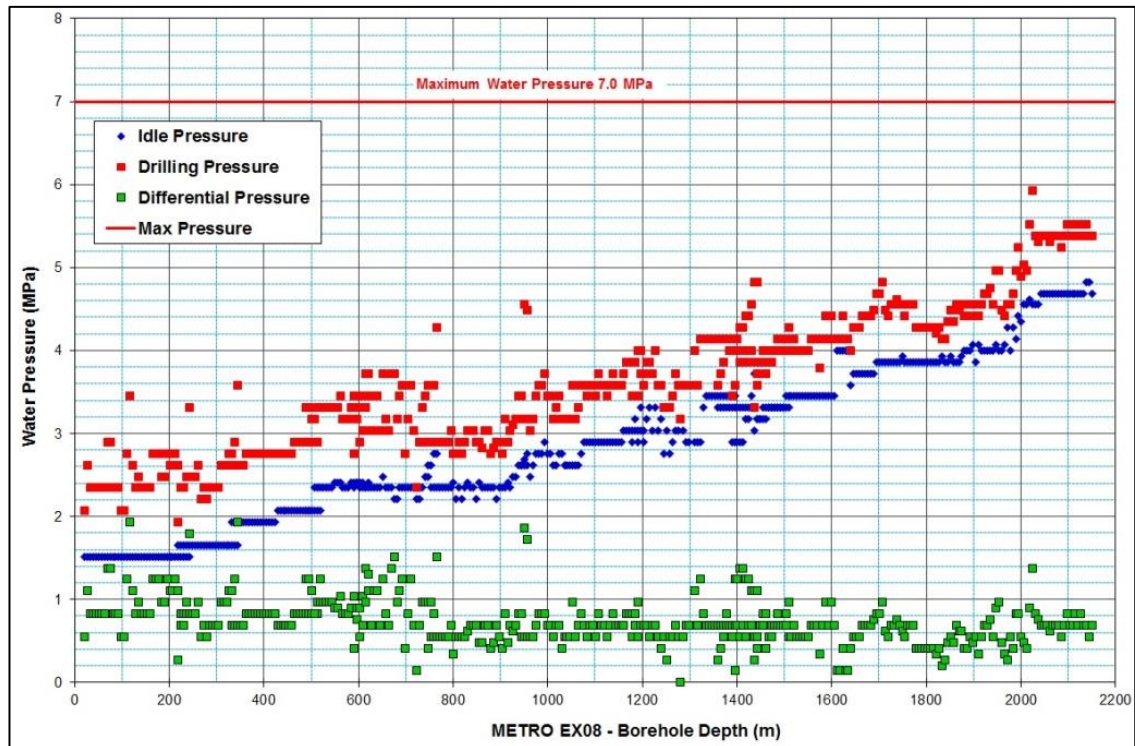


Figure 11: Vertical response curve over 3 m intervals

The usual assessment of DHM steering response has been over 6 m intervals to match the usual 6 m flip-flop drilling method (Hungerford *et al*, 2012). With 6 m intervals unlikely to be used with regular use of rotary drilling, the intermediate 3 m surveys allowed the vertical and lateral response curves to be assessed over 3 m intervals (Figures 12 and 13). These plots are in the order of 50% that established for 6 m intervals with a standard  $1.25^\circ$  bend and 96.1 mm bit configuration. The magnitude of deviations with a  $1.12^\circ$  equivalent bend should be slightly less than half over 3 m.

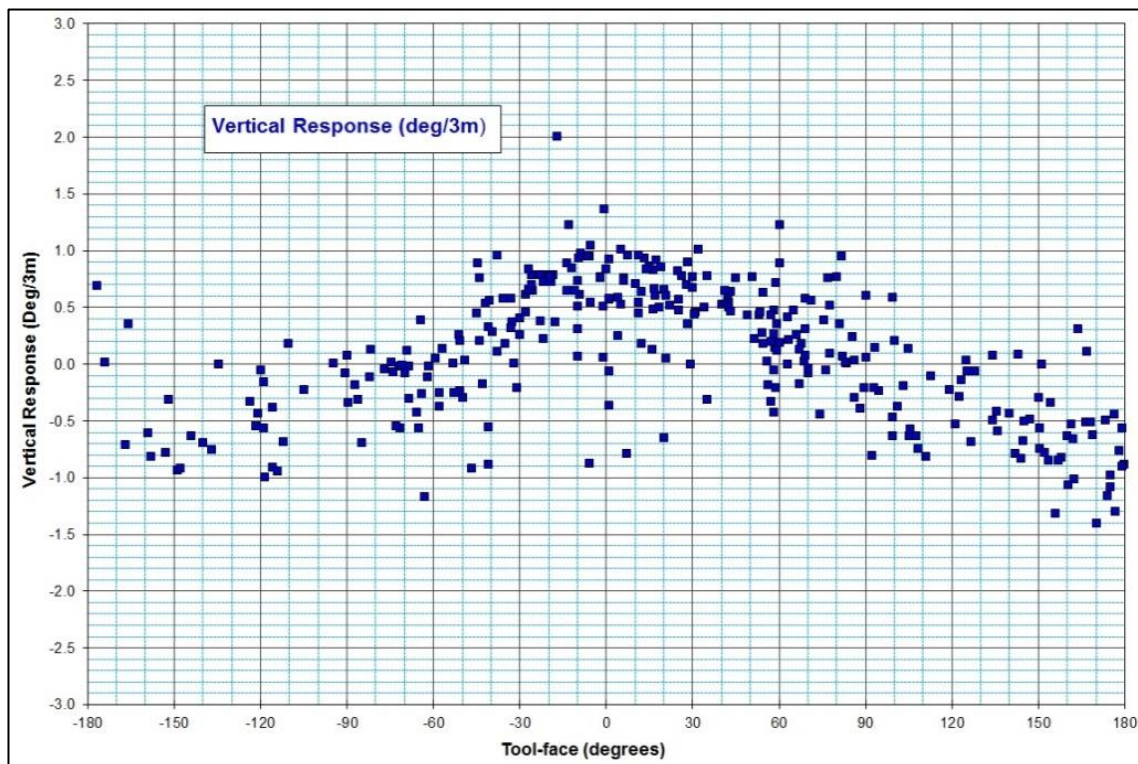
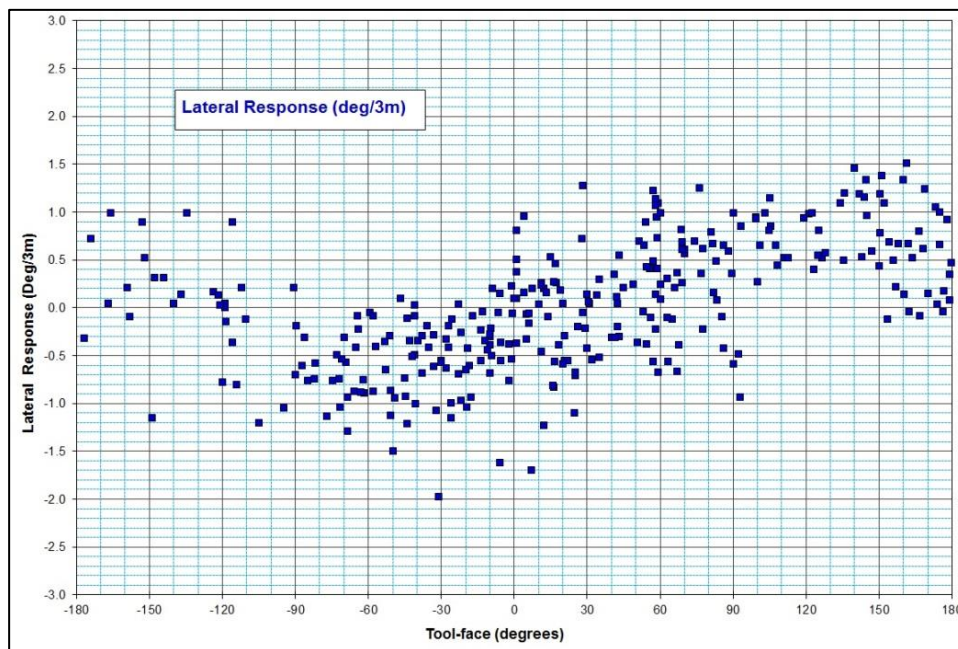


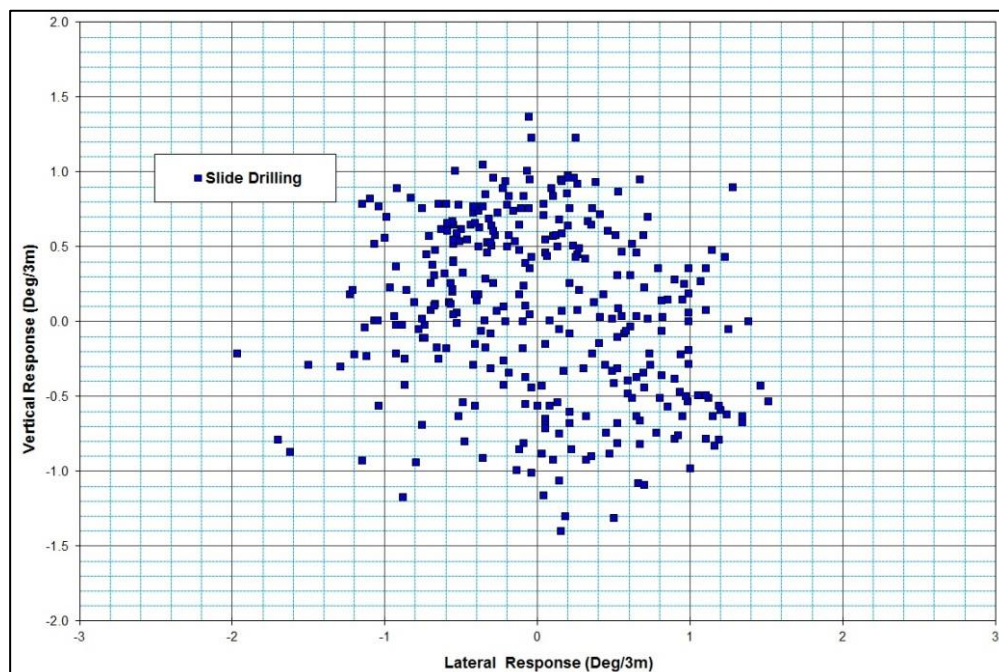
Figure 12: Vertical response curve over 3 m intervals



**Figure 13: Lateral response curve over 3 m intervals**

The deviations over 3 m when rotary drilling after a prior 3 m interval of slide drilling were analysed to determine if the previous slide drilling deflection affected the rotary drilling deflection. No apparent relationship was evident. The same was done for rotary drilling versus depth but again no relationship was evident.

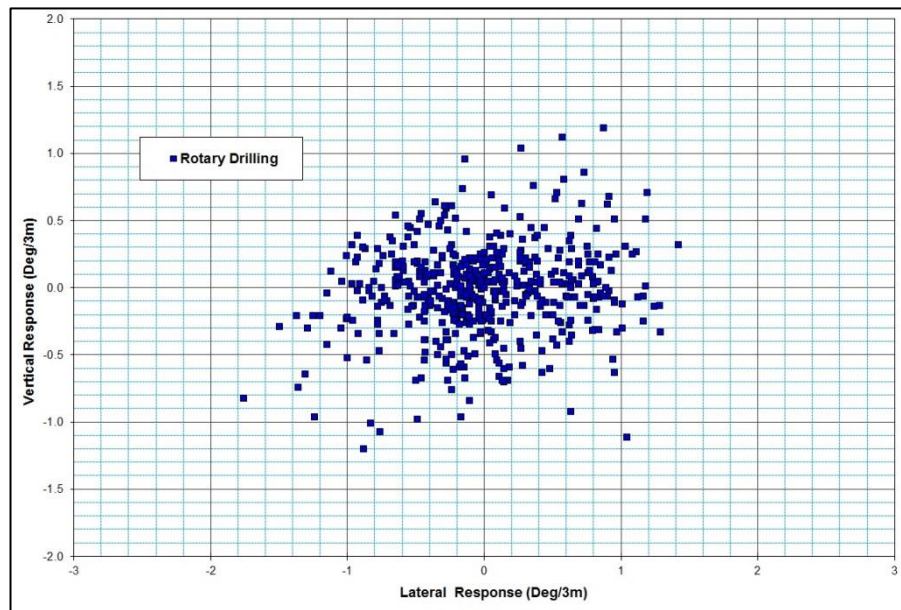
The vertical and lateral deviations over each 3 m interval were plotted for both slide and rotary drilling (Figures 14 and 15). The rotary drilling did not create straight boreholes but the deviations were reduced as seen by the tighter grouping in Figure 15.



**Figure 14: Slide drilling deviation per 3 m intervals**

Although the drillers were limited to rotational speeds below 60 rpm in the pre-drilling instructions, the drillers experimented with traditional rotary drilling variations of increased rotational speed (to 180 rpm) and reduced drilling rate to curve the borehole downwards. Conversely, they reduced rotational speed and increased drilling rate to curve the borehole upwards. The variations in drilling rate are evident in

Figure 10. This was used successfully to extend all boreholes past the no slide depth. The most effective was in borehole DH08 with 408 m being rotary drilled to the final record depth of 2151 m (Table 1).



**Figure 15: Rotary drilling deviation per 3 m intervals**

The drillers also noticed that they were able to manage some semblance of lateral control with the vertical control parameters. Although not recorded until the latest unprocessed drilling, they believed climbing parameters also deflected the borehole to the right and dropping parameters curved the borehole to the left.

The most recent borehole (DH11) has been the most successful with depth drilled before slide drilling could not continue. This borehole is also the borehole with the greatest off-set angle to the target azimuth and has the largest lateral deviation of 166 m to the left. The drilling data has not yet been analysed for this borehole but interest will be in the percentage of rotary drilling used and at what depths in the borehole. This is an indication of improvements in the drillers' skills through exposure and experience in the drilling practice and innovation on the drillers' part. This borehole was drilled with a track mounted Series 1000 with higher thrust capacity.

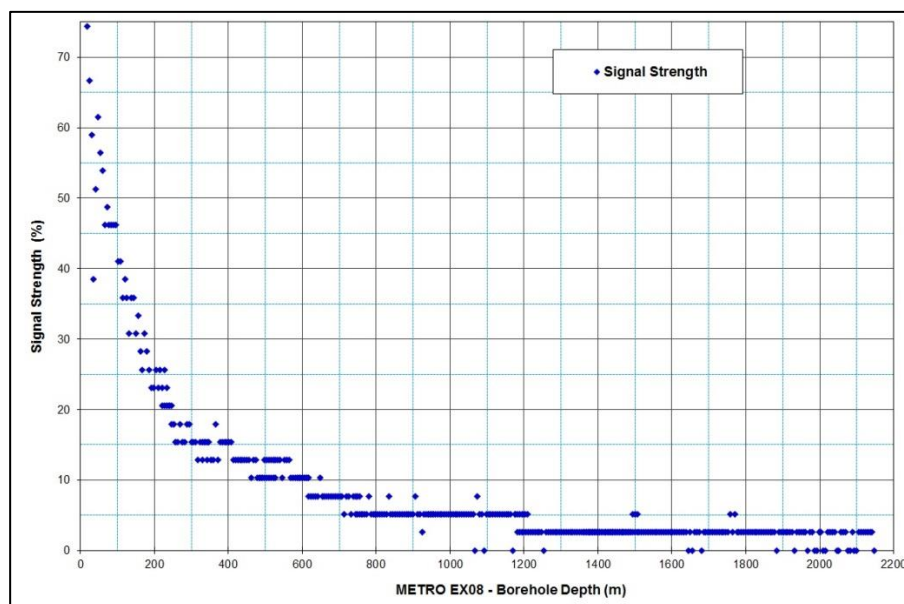
Although the thrust loading is only at approximately 25 % capacity, the rotation pump pressure is at approximately 85 % capacity at depths beyond 2000 m. This is likely to be a limiting factor in determining maximum depth capacity with the current equipment.

The DHM completed six boreholes before being replaced due to bearing pack failure. Wear at the bend is always a problem with DHM drilling but the presence of the 1 mm thick wear pad prevented adverse wear. Some erosion was evident but had not started to penetrate through to the thread at that joint. The PCD drill bit with the repositioned outer cutters that were used over that period showed limited abrasive wear and some chipping on most cutters but not enough to affect the cutting characteristics of the bit.

The survey instrument signal strength reduced rapidly over the first 400 m but from 1200 m, the signal strength remained reasonably constant at 0.5% (Figure 16). The first borehole (EX03) was terminated with survey signal problems. After that, survey signal problems were insignificant with some difficulties only experienced at depths beyond 2000 m with several attempts required occasionally before a signal was received.

With the discontinued supply of the thread grease "Talc Blue" which had been the standard grease in the industry, the non-metallic grease ERTG 9507 had been recommended as a replacement. For this project, DRTG ZN50 grease with 50% metallic zinc within its formulation was introduced. The grease had good adhesion and anti-galling characteristics and with the metallic content, may have contributed to the improved signal transmission.

The drill rods were comfortably pulled from each borehole without the need of rotation to reduce friction.



**Figure 15: Surveying signal strength**

### CONCLUSIONS

Drilling with a combination of slide and rotary drilling was successful in producing a series of boreholes to and beyond 2000 m and located in positions which should provide adequate gas drainage of the gate-roads before development mining commences.

All components of suggested drilling practice were employed to achieve a successful outcome to the project:-There were:

- A larger diameter bit.
- Reduce the effective bend.
- Increase tool-face intervals.
- Rotary/slide drilling.

The straighter drilling provided in the rotary drilled sections reduced in-hole friction and extended the depth to which slide drilling was possible. The reduction in bend magnitude reduced the surging feed usually experienced with slide drilling in long holes. Thrust capacity to overcome friction became the limiting factor on the slide drilling depth rather than repeated stalling of the DHM through surging.

The increase in the bit (and borehole) diameter from the standard 96.1 mm after the first borehole to 99 mm for the remaining drilling would have reduced in-hole friction. The increase in diameter also allowed the DHM with its bend and wear pad configuration to rotate in the borehole without flexing the DHM. This would have reduced friction wear on the bend and reduced the potential of early failure.

Rotary drilling dramatically reduces the thrust friction on rods sliding in a borehole. When slide drilling capacity is reached, rotary drilling can effectively continue the drilling with some lateral and vertical control. Then an intersection with seam roof or floor will terminate the borehole if deviating too far off-line does not terminate the drilling beforehand.

Drill skills and experience in the use of rotary/slide drilling developed during the duration of the project.

Rotation capacity and water pump pressure capacity will be the limiting factors for drilling depth capacity when in rotary drilling mode.

Good profile definition from most boreholes provided the mine with definitive RL information over the area of drilling. In the add-on value of exploration provided by in-seam directional drilling, the areas of the longwall gate-roads were shown to be free of structures, which may have adversely affected mining operations. No adverse drilling conditions were experienced which might adversely affect gas drainage from the area.

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**REFERENCES**

- Eade P, 2002. Case study – Outburst and gas management, *Proceedings Underground Coal Operator's Conference* (ed: N Aziz), University of Wollongong, pp 105. February, 2002, pp 105 -113. <http://ro.uow.edu.au/coal/199/>
- Gray I, 1991. Limits of directional drilling for coal exploration, *Australian Coal Association Underground Coal Mining Exploration Techniques*, Brisbane 8-9 November, 1991.
- Gray, I, 1992. Development of in-seam drilling for the production of methane, *Symposium on Coalbed Methane Research and Development in Australia*, Coalseam Gas Research Institute, James Cook University of North Queensland. Townsville, 19-21 November 1992.
- Gray, I and Daniel, B, 2000. Testing of and research into drill rod joints for longhole drilling, *Final Report ACARP Project 4039*, June, 2000.
- Hungerford, F, Kelly, M, Saghabi A and Williams R, 1988. Long-Hole Drilling for Gas Emission Control at Appin Colliery NSW, Australia, *Fourth International Mine Ventilation Congress*, Brisbane, Queensland, July 1988.
- Hungerford F, 1995. Status of Underground Drilling Technology, Keynote Address, in *Proceedings of the International Symposium cum Workshop on Management & Control of High Gas Emission and Outbursts in Underground coal mines*, Wollongong 20-24 March 1995 pp. 397-404.
- Hungerford F, Ren T and Aziz N, 2012. Directional Control in Longhole Drilling, *2012 Coal Operators' Conference*. University of Wollongong, Feb 2012. pp.268-276. <http://ro.uow.edu.au/coal/415/>
- Kravits, S, Rusby, B, Reilly, J and DuBois, G, 1999. Reaching greater depths – the maximization of in-mine horizontal longhole technology, *Coal Age Magazine*, 1999.
- MacCabe, M and Hellyer, A, 2013. Reduction of outbursts through directional drilling, *MEMMES 60th Anniversary Convention*, 2013.
- Valley Longwall P/L, 2002. Unpublished drilling records, borehole S7TG-B1, *Newlands Colliery*, February, 2002.
- Walsh, R and Hungerford, F, 1993. Exploring longwall domains using directional longhole drilling. Longwall in Australia continuous improvement or crisis, *ACIRL, Underground Mining Seminar*, Sydney, Australia, 19-20 November, 1993.