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Directional control in longhole drilling

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DIRECTIONAL CONTROL IN LONGHOLE DRILLING

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ABSTRACT: Directional drilling has provided the coal mining industry with a means to position in-seam boreholes to achieve goals such as gas drainage, exploration and inrush protection. The evolution of the technology has progressed to a point where most drilling operators use the standard down-hole drilling configuration which has proven effective in most applications. Survey techniques have been modified to reduce the distance between bit and survey point without consideration of the effects on survey accuracy, driller skills and data collection. Data from two long in-seam boreholes is analysed to show the response curves of the standard down-hole configuration. An indication of the effects of in-hole friction, of feed pressures and limitations put on the eventual borehole depths is shown.

INTRODUCTION

Directional drilling has given the mining industry the ability to place boreholes in designed locations to achieve specific goals such as gas drainage, exploration, barrier proving and water drainage. This has been possible through the use of Down Hole Motor (DHM) drilling which provides the ability to off-set the direction of drilling and surveying to accurately locate the borehole and orientate the DHM for steering. The off-set provided by the configuration of DHM bend and bit diameter has to be matched with the drilling environment to provide the ability to control the borehole trajectory and azimuth. Because of the variety of drilling environments likely to be experienced when drilling any long hole within a coal seam, this configuration is usually set to manage the most adverse environment.

Surveying and drilling practices have evolved to suit the requirements at each mine. The ability to drill long holes becomes an exercise in directional control with drilling practices to limit the in-hole friction which increases as a borehole increases in depth. Reviewing these practices and resultant frictional effects is intended to refine driller skills and practices to improve borehole drilling efficiency and depth capacity.

DIRECTIONAL CONTROL

In-seam drilling with DHMs has evolved into an industry standard over the past 25 years. Driving high pressure water through the DHM provides the rotation and torque while the off-set of the bend/bit Outer Diameter (OD) configuration provides the ability to steer a borehole.

The off-set of the bit at the front of a DHM is usually provided by a bend (or bent sub/housing) installed between the power section and the bearing pack. The off-set of the bend can be enhanced by the addition of an off-set (or kick) pad attached to the bend or the addition of a tungsten carbide wear resistant coating. In any case of adding to the thickness of the 73 mm OD DHM, the final thickness through that point should not exceed the Internal Diameter (ID) of HQ rods which may be required to over-core should the system become bogged. The use of an extension between the DHM and bit also provides additional off-set.

Directional control (in the first instance, vertical control) is only deemed to be provided if the DHM has the ability to climb when orientated through a range of upward facing positions. To do this, the off-set of the DHM must exceed the oversize that exists between the bit diameter and the OD of the DHM. To provide lateral control, the off-set must be of sufficient magnitude to provide a range of orientations either side of vertical that allows lateral deviations while still having the ability to climb.

The configuration, in the mid 1980's, with the 74 mm Slimdril, 1-2 lobe DHM was to use a ¾ ^{o} bend with the standard 89 mm PCD bit that was available (Hungerford, *et al*., 1988). Using the Surtron electronic survey instrument available at the time to survey at 6 m intervals with the surveying location positioned 6 m behind the bit, each survey point matched the location at which the orientation of the DHM (also

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referred to as Tool Face) was changed. The change between surveys represented the change (or response) in both the vertical and horizontal planes created by the previous DHM orientation. Over the course of drilling a long hole, combining these changes for the various orientations, response curves are established in both vertical and lateral planes. The first such response curves were compiled from the drilling of the first 1000 m in-seam borehole at Appin Colliery (Hungerford, *et al.*, 1988) (Figures 1, 2). From this and subsequent drilling, a drillers guide was established as shown in Figure 3 and is included in the Appin Drilling Manual (BHP, 1996).

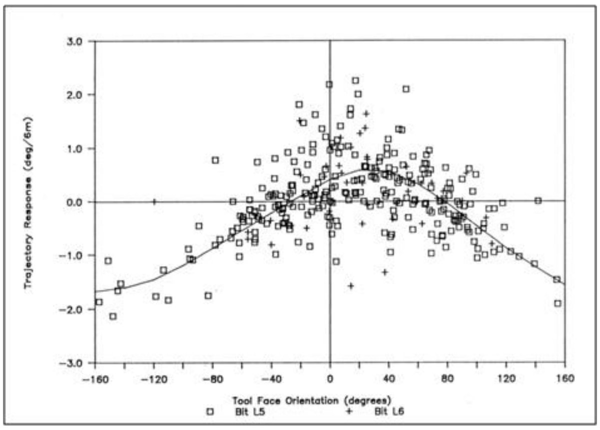

Figure 1 - Vertical response - ¾° bend, Slimdril DHM

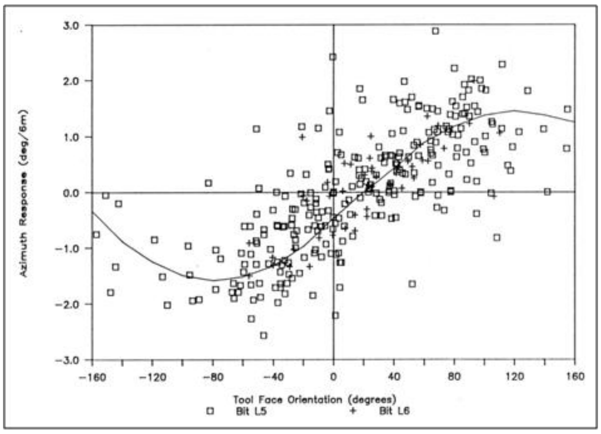

Figure 2 - Lateral response - ¾° bend, Slimdril DHM

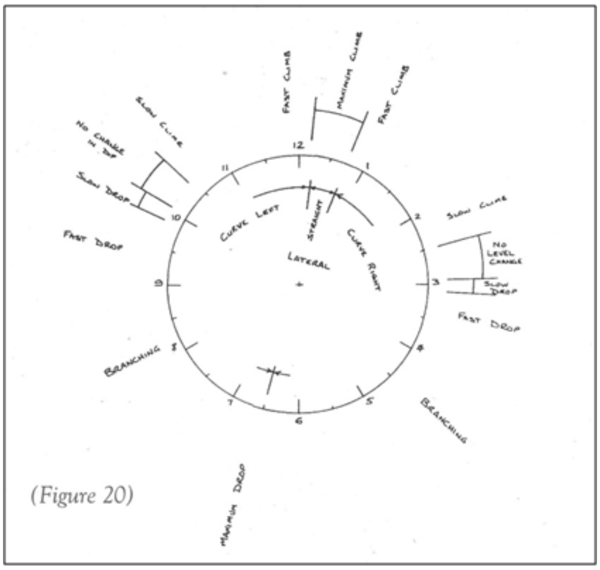

Figure 3 - Steering guide - ¾° bend, Slimdril DHM

All the initial DHM drilling was done in slide motion. Attempts to use a combination of rotation with slide (Rotary/slide drilling commonly employed by surface drilling operations) led to the borehole dropping rapidly into the floor of the seam floor from which it could not be recovered in slide motion with the limited climbing ability available with the DHM configuration.

DEPTH CAPACITY

Using the early configuration with the 89 mm bit, the feed rate from the start of a borehole was steady out to the 60 m depth. From that point, it was noticed that the feed started to surge with the surge of water pressure to match that of the feed. The surging increased to the point that the spikes in the water pressure exceeded the "relief" pressure setting of the water pump relief valve and the DHM would stall. To prevent stalling, the feed rate was reduced to limit the surging and thus the magnitude of the water pressure spikes. As the borehole was extended in depth, the surging progressively increased, resulting in progressively slower feed rates being used to prevent stalling. Very slow feed rates were being used to achieve the first 1000 m borehole and subsequent cross-measure/in-seam drilling in the Balgownie Seam only achieved 923 m and 870 m respectively (Hungerford, *et al*., 1988). In each case, surging feed and slow penetration rates caused the termination of drilling while the maximum available feed pressure had not been reached. This indicated that borehole depths were limited by the surging feed in the borehole. Drill rigs that operated under a constant feed rate using a hold-back valve on the return line did not suffer as badly, with surging, as systems with constant pressure feed and no restriction on the return line.

This surging characteristic contributed to the effect of the axial load required to overcome the frictional effects in the hole causing the rods to flex towards the outside of the curves in the borehole. As the axial load increases, the rods are pushed out against the outside of each curve until the friction is overcome. As friction is overcome to allow the rods to slide forward, they return to the centre position at the bottom of the borehole resulting in the bit surging forward at the face. This surge forward of the bit into the face rapidly increases the torque loading on the bit and DHM, resulting in spikes in the water pressure.

In an attempt to reduce in-hole friction, an increase in bit diameter to 95 mm was proposed. When the bit manufacturers were approached to produce a 95 mm PCD bit, they indicated that the standard diameter of the PCD bit used for open-hole drilling prior to HQ coring was 96.1 mm. This bit was sourced and combined with the newly available 73 mm OD, high-torque, low speed Accu-dril DHM (4-5 lobe). To increase the off-set of the DHM to provide vertical control, the magnitude of the bend was increased to 1.25°. This configuration provided a DHM offset of 17.5 mm which, when combined with the 11.5 mm oversize of the 96 mm bit, provided 6 mm lift to the underside of the bit when the bend of the DHM was in the 12 o'clock position. This configuration was first used on an exploration project at North Cliff Colliery with improved penetration rates, surging noticeably reduced and all boreholes reaching design depths out to 900 m (Walsh and hungerford, 1993). Two longholes (not restricted by structures) were then drilled to the north. In the first borehole of these boreholes, drilling achieved a depth of 1 250 m before closer attention to bends in the borehole led to a depth of 1 533 m being achieved with the second borehole. These depths were achieved with Eastman single-shot wire-line surveying at 18 m intervals with the drillers having to rely on the response curves modified from those of the previous configuration (Hungerford, 1995) to plan their DHM orientations between surveys.

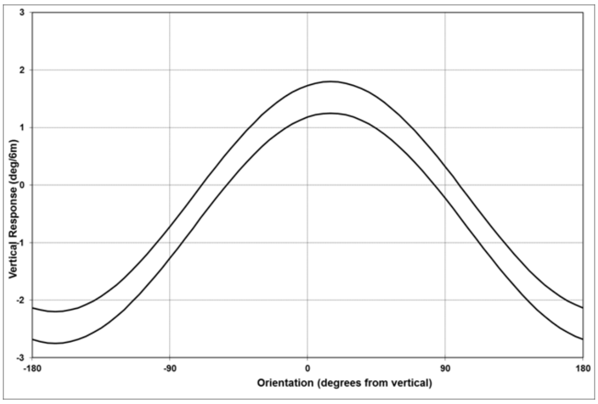

Figure 4 - Vertical response guide - 1.25° bend, Accu-dril DHM

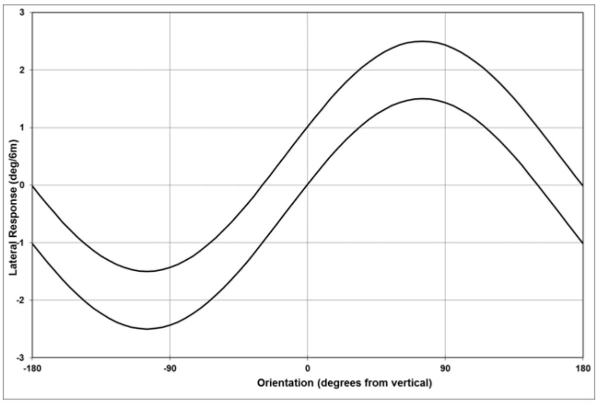

Figure 5- Lateral response guide - 1.25° bend, Accu-dril DHM

STEERING LIMITATIONS

Access to electronic survey systems was limited to developmental, ineffective or unreliable systems.

The majority of surveying was with the Eastman, single-shot, wire-line survey tool which suffered increased delays with depth and reliability problems with the operation of the tools and wire-line. Because of these characteristics, survey intervals were increased to 18 m involving three orientation changes with the drillers having to design their drilling between the survey points. DHM responses were based on the original responses established with the Slimdril (¾° bend) and 89 mm bit.

In this environment, drillers of that era developed a high knowledge of DHM performance, orientation responses and rig performance to progressively plan and nurture drilling in a longhole rarely matched by the current drillers of using the latest survey technology.
The development of the Directional Drill Monitor using Modular Electrical Connected Cable Assembly (DDM-MECCA) gave the industry a survey system that allowed reliable surveys at regular 6 m intervals with no time delays out to depths beyond 1500 m. The DHMs used at that time were the regular 73 mm Accu-dril DHM and the 2-3/8" Drilex DHM with a 3/4° bend and 10 mm kick pad. With the Drilex being a steel motor, surveying was located 3 m behind the DHM (6 m behind the bit) to maintain a non-magnetic survey environment. Drillers were able to develop an understanding of both vertical and lateral responses in a particular drilling environment and anticipate the survey result at the bit before planning the next 6 m of drilling.

SURVEY POSITION

With the eventual discontinued use of the steel Drilex DHM, all drilling reverted to using the non-magnetic Accudril DHM. With that, drilling departments were able to move the survey point up to the back of the DHM (3 m behind the bit) and still apparently be in a non-magnetic survey environment. The reasoning behind this move was supposedly to provide better directional control (being only 3 m behind a potential stuff-up) which did not require as high a level of driller skills so it would be easier to train new drillers to a level necessary to directional drill.

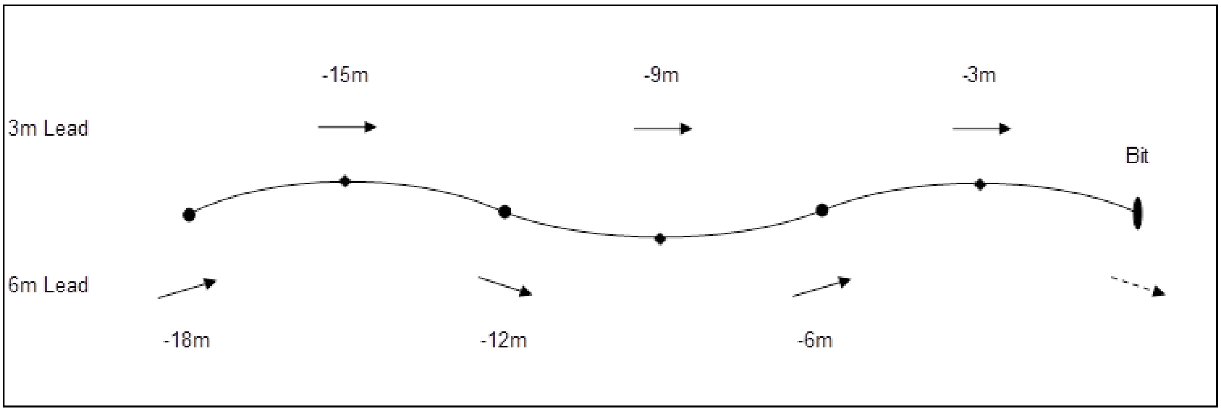

Figure 6 - Survey positions with 6 m orientation changes

Although drilling departments have managed operating with this system without adverse effects, several limitations have been identified:

- All survey calculations are based on a consistent curve between survey points (Figure 3). This occurs when a consistent orientation has been used between survey points as is the case with surveys 6 m behind the bit. With surveying 3 m behind the bit and using 6 m orientations intervals, the survey point is located at the orientation transition point. The change in survey results represents 3 m of the previous orientation and 3 m of the current orientation. The resultant survey calculations produce a nominal location of the borehole which relies on a random average of which the accuracy is not known. An interval of "flip-flop" drilling each side would be represented by relatively consistent surveys which don't show what could be 2.5°-3.0° changes if surveyed at the transition points;
- In any drilling environment, response curves can't be established to provide drillers and designers with knowledge to assist steering of the drilling. Limited knowledge can be gleamed from sections of holes where the same orientation has been used on consecutive survey intervals, as in drilling around an extended curve;
- No accurate assessment of the magnitude and location of significant bends in a hole can be made to assess the potential problems with any subsequent over-coring operations should the rods become bogged;
- In cases of unusual thrust pressures required during the drilling of a borehole, an assessment of the frictional effects due to the accumulated effects of bends in the hole can't be determined;

- The overall effect is to limit the skills developed by directional drillers.

This knowledge would assist in the assessment of the equipment, the drilling parameters and practices required to improve drilling performance and depths achieved. It would also assist in driller training.

The increased use of steel DHMs for both stone and coal drilling requires the survey point to be moved back 3 m behind the DHM (6 m behind the bit). Drillers with limited experience of directional drilling with this configuration (surveying 6 m behind the bit) would benefit from access to support information such as response curves.

Several cases exist of boreholes being found out of position. With calibration results being verified, the unusual survey results have put some doubt of the non-magnetic environment expected to exist directly behind an apparent non-magnetic DHM. Some trial calibration procedures involving the introduction of a DHM to the calibration environment has shown similar discrepancies. The inconsistent nature of these results would indicate that alternative practices would need to be put in place for accuracy sensitive projects.

Borehole performance - Case 1

Comprehensive data collection was undertaken during the drilling of a long in-seam exploration borehole in the Bulli Seam on the South Coast. As drilling advanced, the seam profile was progressively defined with roof intersections (Figure 7). The grade of the seam along the line of the borehole was relatively consistent out to 900 m where it flattened through an area of suspected faulting before rolling over to continue on a similar down grade.

The borehole was maintained along a Target Azimuth line with only two deviations more than 1 m from this line (Figure 8). The left/right and up/down deviations created by the changes in DHM orientation (Tool Face: expressed as clock face hours) every 6 m are not evident on these plots.

In the vertical plane, the change in borehole pitch over 6 m achieved by each Tool-face setting used has been plotted to create a Vertical Response Curve (Figure 9). The plot indicates a range of Tool Face settings between 10:10 and 3:30 which achieve a positive (climb) response with a maximum of 2.4^{o}/6 m achieved with a Tool Face of 12:40. Negative (dropping) responses are achieved between 3:30 and 10:10 with a maximum drop of 3.0^{o} / 6 m at 7:00. Also evident is the variation in responses achieved by the various Tool Face settings. This is attributed to the non-homogenous coal strata environment being drilled and the various pitches relative to the bedding planes.

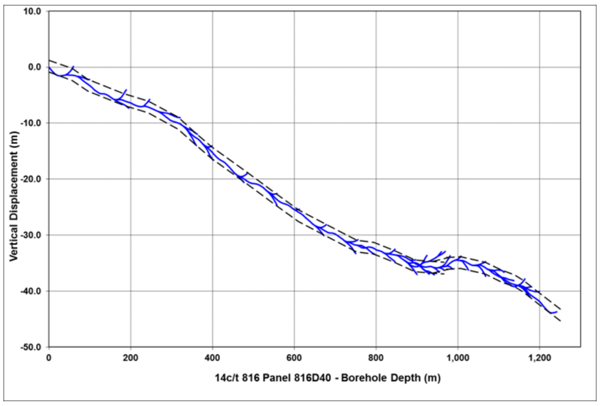

Figure 7 - Borehole and seam profile (816D40)

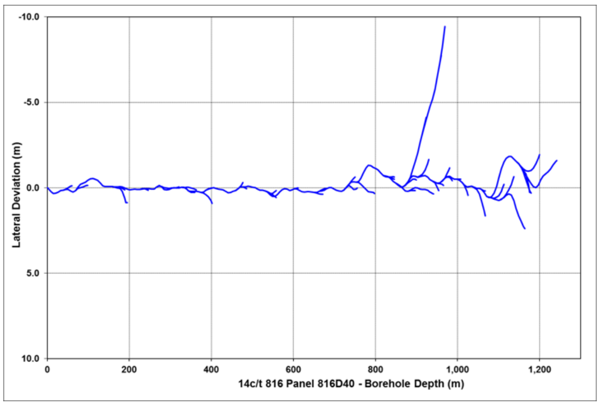

Figure 8 - Lateral deviation (816D40)

In the horizontal plane, a similar profile curve has been created as a vertical response curve (Figure 10). Positive lateral curve (right) was achieved between 12:50 and 7:00 with a maximum of 2.1^{o} /6 m at 4:00. Negative curve (left) was achieved between 7:00 and 12:50 with a maximum curve left of 2.4^{o} /6 m achieved at 10:10. The stronger curves to the left could be attributed to the effects of cleat. As expected, the Tool Face settings which achieved no lateral deviation (12:50 and 7:00) were those which achieved maximum climb and drop in the vertical plane.

The progress of the borehole was expected to be restricted by the increased surging feed, leading to progressively slower penetration rates. In this case, the penetration rate started at a comfortable 1.2 m/min and slowed progressively out to 600 m, from which a rate of 0.80 - 0.85 m/min was maintained (Figure 11). Although the depth of the hole was limited by the number of drill rods available on site, the drillers felt that the maximum feed capacity of the rig was being reached beyond 1 200 m.

The plot of feed pressure versus borehole depth (Figure 12) indicates that the increase in borehole friction is not linear. The plot shows that the final depth of this borehole would have been limited eventually to 1 300 m if drilling had continued until the max available pressure had been reached. There are three trends in the plot: 0 - 400 m, 400 - 1 150 m and 1 150+ m. The increasing trends beyond 400 m indicate that the increases in axial load in the rods must have an increasing effect on friction as borehole depth increases. The extent of the relationship between borehole depth, axial load, general curves and short 6 m orientation change curves is not known.

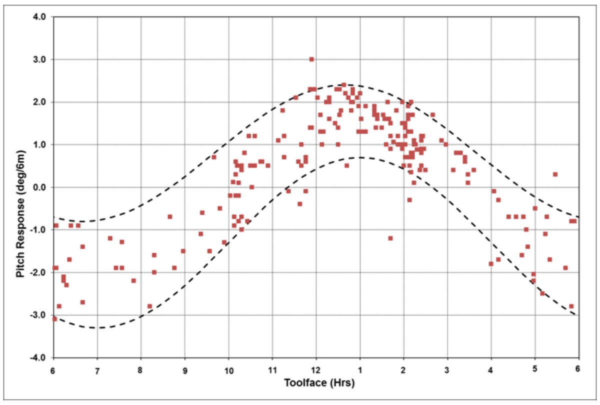

Figure 9 - Vertical response curve (816D40)

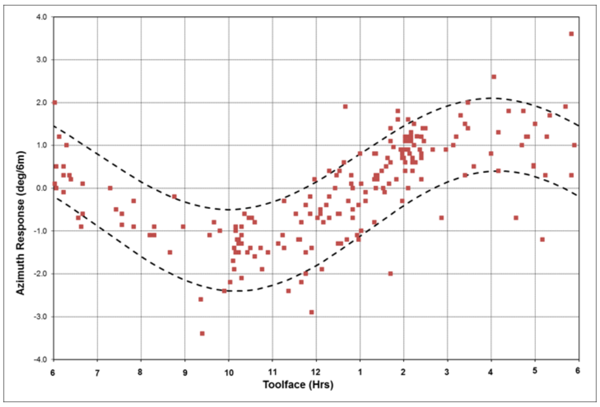

Figure 10 - Lateral response curve (816D40)

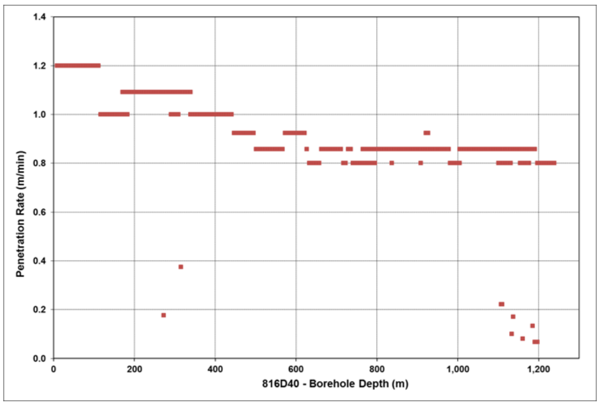

Figure 11 - Penetration rate (816D40)

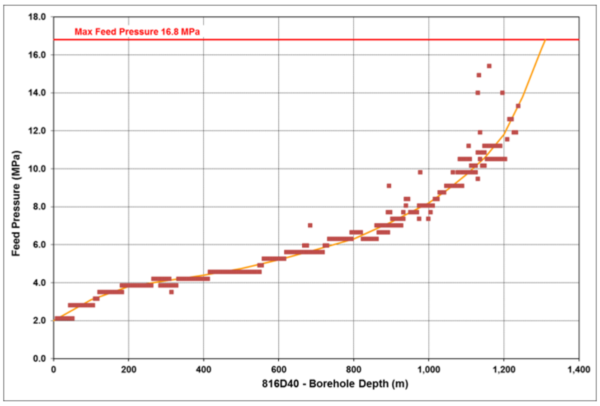

Figure 12 - Feed pressure (816D40)

Borehole performance - Case 2

A second long exploration borehole was attempted in different conditions in a coal seam in the Hunter Valley using the same drill rig and equipment. This borehole was intended to cross the adjacent longwall block and run along the gate-road pillars with roof cores being taken at pre-determined intervals (Figure 13). Normal exploration practice was employed of progressively defining the profile of seam (Figure 14). The Case 2 borehole starts from the south-east corner of Figure 15 and curves around towards the north for two legs to extend along a Target Azimuth of 348.0°. During drilling around the main lateral curve, over the interval 150-250 m, the borehole had a tangential intersection with a fault identified previously by an in-seam borehole. Drilling crossed the original exploration borehole in two places and was extended to 795 m, before water was lost into the original borehole preventing further drilling from that point. A second leg was designed to branch from 342 m, continue along the azimuth of the borehole at that point out to the left then curve around to continue along the target azimuth a further 25 m to the left (Figure 16).

At the point of losing water into the previous borehole, drilling had slowed with regular stalling of the DHM due to what the drillers thought was very hard drilling. The second leg was extended to 867 m with similar conditions being experienced beyond 831 m depth. The plot of Feed Pressure versus Borehole Depth (Figure 17) on the first leg showed a pattern similar to that of Borehole 816D40 but with a more rapid increase beyond 400 m. A further rate increase in Feed Pressure beyond 760 m, when extrapolated, indicated that the maximum feed pressure capacity of the rig would have limited the final depth to 820 m in this leg.

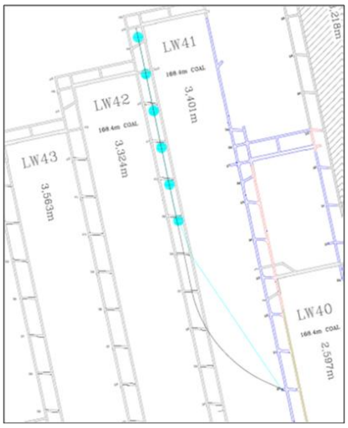

Figure 13 - Plan - proposed borehole MG40-30-1

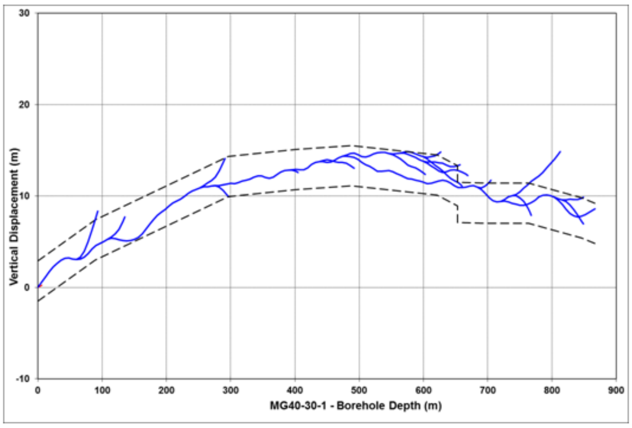

Figure 14 - Borehole and seam profile (MG40-30-1)

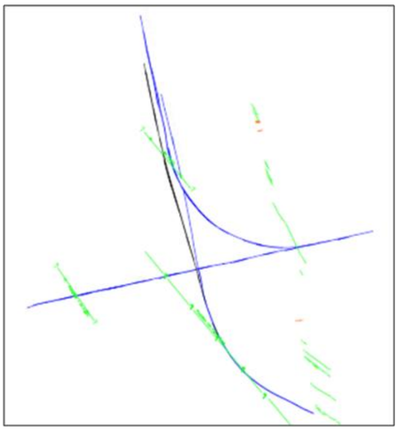

Figure 15 - Plan - borehole MG40-30-1 (with WW07-1)

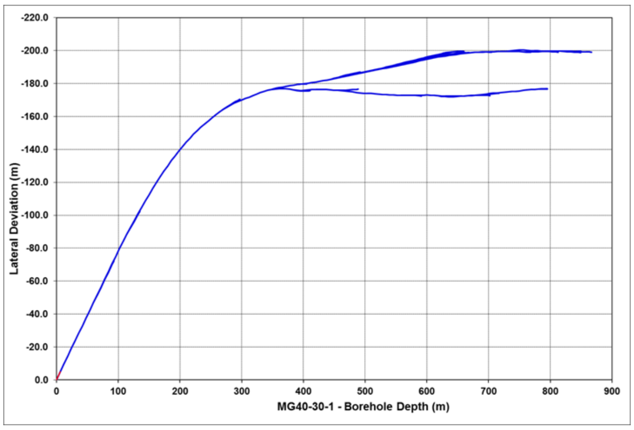

Figure 16 - Lateral deviation (MG40-30-1)

Conditions different from the 816D40 drilling included:

- an initial Entry Heading 54.4° offset from the Target Azimuth;
- a curve with an average curve rate of 1.0° / 6 m from the entry heading to target azimuth;
- the presence of small clay bands within the seam;
- a tangential intersection over 100 m between 150 m and 250 m with a fault zone;
- the presence of a second fault zone at 653 m which was crossed.

When comparing the plots of feed pressure versus borehole depth for both boreholes (Figure 18), the shape of the trends are similar but with the increased rate of change for the MG40-30-1 borehole beyond 400 m. The initial increase in the rate of change of each occurred from the feed pressure of 4.1 MPa while the final rapid increase in rate for both occurred from a feed pressure of 12 MPa. In either case, drilling out to depths of 700 m, did not present difficulties with feed.

The appearance of suspected hard strata and regular stalling of the DHM was similar to previous experiences with the smaller bit diameter. In both cases, the ability to drill further was restricted by both surging in the borehole due to friction and the maximum feed capacity of the rig being reached.

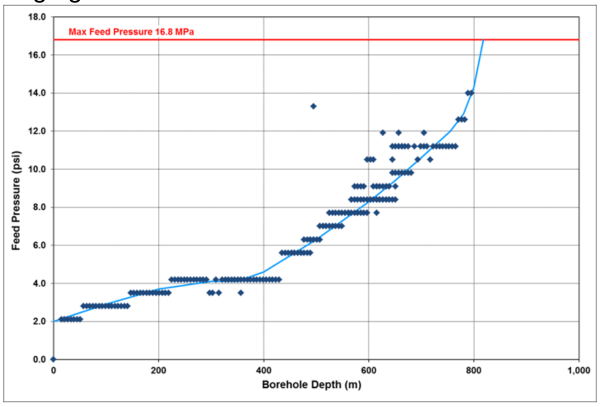

Figure 17 - Feed pressure (MG40-30-1)

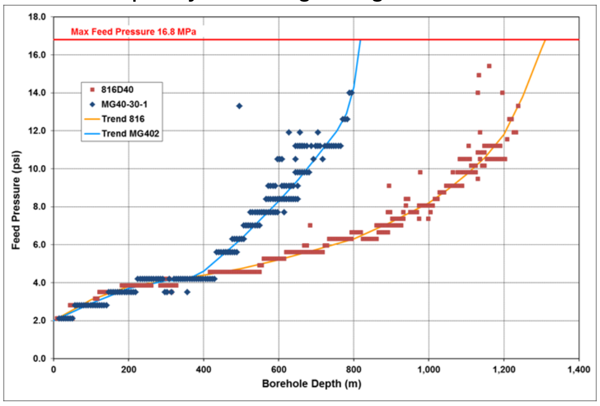

Figure 18 - Feed pressure (816D40 & MG40-30-1)

FUTURE RESEARCH

The aim of future research on the subjects covered in this paper is introduce drilling and surveying practices in Vally Longwall International (VLI) to allow the collect more suitable data to establish "standard" response curves for each drilling environment and the variety of DHMs and configurations being used.

Emphasis will be towards data collection and analysis to determine:

- the effects of overall curves in boreholes and their rates of curve on in-hole friction effects and borehole capacity;
- the accumulated effects of the smaller bends in the hole created by orientation changes, the number of bends and where they are in the hole;
- the effects the initial Entry Heading off-set angle of the standpipe from the Target Azimuth;
- effect of maintaining design curve versus over-shooting or under-cutting the design lateral deviation;
- a comparison of feed-in pressure to pull-out pressure in each longhole.

With this data collection and processing, the VLI drillers will be exposed and trained in improved drilling practices and data collection and explained to them the results of the research. Training programs will be enhanced with this knowledge.

CONCLUSIONS

At this stage, drilling in one borehole may extend to a depth several hundred metres deeper than a previous borehole in the same environment without any apparent changes in drilling parameters. The aim is to develop an understanding on the aspects that affect in-hole friction to improve drilling efficiency and depth capacity.

More suitable data is required to establish the characteristics of each DHM configuration in the various environments experienced with in-seam drilling. Providing a DHM configuration specifically suited to each longhole project will limit in-hole curvature to enhance the borehole depths regularly achieved.

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