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Directional drilling in unstable environments

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ABSTRACT

Directional drilling has been established in the coal industry as a viable means of gas drainage, exploration and water management. But the environment in and around coal seams is not always conducive to stable conditions while drilling and borehole stability after the drilling has been completed. This paper identifies the conditions which cause unstable drilling conditions and the various means which are used to attempt to manage or bypass those conditions. Ultimately, equipment does become bogged in these adverse environments and requires recovery by over-coring.

1. Introduction

Directional drilling has been developed and evolved as a safe and reliable means to position boreholes in coal seams and the surrounding strata to allow gas drainage, exploration ahead of development and water management [1–7]. But any drilling requires a stable environment to provide stable boreholes while drilling and for those boreholes to remain open through their functional life.

Coal seams have been subjected to numerous and various forces which create areas of fractured coal and unstable strata. Drilling into or through areas of unstable ground has always been a major problem for drillers. Even with precautions, caving can occur and bog the drill string in the borehole. This can result in the loss of drilling performance and equipment, project delays while attempts are made to retrieve the string, and steel left in the coal seam to be later intersected by mining.

The cost of equipment at risk is increasing as drilling technology improves and more expensive equipment is being used in-hole. Before any drilling is undertaken, it is logical to assess and define the potential drilling environment. Drilling projects can then be planned to manage the environment and to successfully complete the project while avoiding the adverse effects of intersecting unstable drilling conditions.

Unfortunately, even with the best planning and prior knowledge, drilling equipment does get bogged with potential loss at high expense. With increased exposure to adverse drilling conditions and bogging events, over-coring to recover bogged equipment has become an established practice.

2. Drilling environment

When drilling is penetrating strata, the strata is expected to be stable and competent enough to support the cylindrical opening of a borehole. The strata around the opening should be able to resist the surrounding stresses and any adverse effects that contact with water may have to that strata. But in the course of in-seam drilling, adverse and unstable environments are encountered and must be managed.

Several different forms of unstable ground have been encountered and defined with a variety of means developed to negotiate the zones [8].

2.1. Mylonite zones

Mylonite zones are areas of pulverised coal held in place by the surrounding coal and can be in small vertical or horizontal bands or in much larger volumes. This coal has no structural strength and collapses or can be propelled by gas pressure into any borehole intersecting it. The smaller bands can be negotiated usually with no indication at the drill site of the intersection. The problem exists with the larger volumes collapsing or being propelled into a borehole and jamming around the drill rods or blocking a borehole.

In some cases these areas can be cleared with very slow or no penetration and continual flushing until a stable cavity has been established. The areas can be bypassed by branching and choosing an alternate horizon or lateral position. If the rods do become

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stuck, removing the water pressure may ease the pressure on the blockage and allow easier extraction.

2.2. Fractured coal

Boreholes intersecting areas of faulted coal can dislodge large volumes of fractured coal. This can jam around the drill string at the location of the faulting or be flushed out to settle in out-bye cavities or the standpipe and jam the rods there. The rods may jam only when feeding in as the debris is jammed against the in-bye edge of the cavity while being free to pull out. The reverse can happen with large pieces jammed against the out-bye edge of cavities by the flow of flushing water out of the borehole.

The mode of negotiating these conditions is usually the same as for mylonite zones. In most cases, working the bit back through an area helps to break up larger pieces for easier removal by flushing. If the area has been identified as extensive, it is better avoided with drilling.

2.3. Very high stress areas in coal

High stress concentrations can be present in the seam and surrounding strata due to abutment loading from longwall advances, new drivages or depth of the coal seam. This can cause the borehole to crush either as it is drilled or at some later stage. This has occurred while drilling a standpipe hole to 6 m, immediately after directional advances from the end of a standpipe or as it passes through a specific stress zone. Drilling through these zones is usually unsuccessful as it is difficult to stabilise them with flushing and reaming. When a zone is defined as localised around a panel, the initial section of hole can be drilled in stone to intersect the seam at some (trial and error) defined distance from the drill site to avoid the zone. Casing is not usually an option as the initial drilling can't complete the borehole into which the case is to be installed.

2.4. Fault zones

Fault zones usually contain components of all three previously described unstable environments. Where a seam displacement has occurred, the fault plane usually contains fault gouge similar to mylonite and the adjacent strata is likely to be disturbed to some extent. The surrounding strata is also likely to be under additional localised stresses. Reverse faults tend to be more disturbed than strike-slip and normal faults. The extent of disturbance and localised stresses is usually proportional to the magnitude of the fault displacement.

2.5. Dyke cinder

Cinder around dykes can be hard and presents drilling problems because of difficulty in penetrating the strata and the potential of damage to drill bits.

The common experience is for cinder to be in a granular form and to behave similarly to mylonite when penetrated by drilling. The extent of the cinder can vary from centimetres to several metres thick. The differences compared with negotiating mylonite zones are the light gritty nature of the drill cuttings and the flushing colour is light grey.

2.6. Soft clay dykes, sills and bands

The characteristics of the dykes present in coal seams vary greatly depending on the extent of weathering. Hard dykes can be very difficult to penetrate with Polycrystalline Diamond (PCD) bits and require diamond coring drilling. This material does not present unstable conditions after drilling.

Dykes which have undergone weathering have usually decomposed to a clay material which can be relatively firm when first penetrated but rapidly soften and can squeeze into the borehole after contacting with water. Some dykes can be stabilised by progressively flushing through to create a stable cavity. Boreholes drilled at an upwards angle through dykes are generally more stable as they do not have water lying in them to allow continual swelling of the clay.

Cases have been experienced where the dyke has been penetrated comfortably and the rods are free to push and pull until water pressure is applied and this forms a hydraulic clamp. Releasing the water pressure releases the rods. Drilling is very slow as penetration or rotation is difficult once the flushing water is applied.

Major clay bands within the seam are best treated as a boundary to the drilling as is the case with the seam roof. Intersections with a band are used for positioning the borehole within the seam with the borehole stopped at the intersection and continued after branching. Because of the likely low-angled intersection and prolonged contact, it is difficult to stabilise an extended length of borehole in clay with continual flushing and reaming.

Alternatives used to negotiate through clay strata have included:

- Drill HW casing through a dyke if close to the borehole collar and drill through the casing. This usually involves drilling the directional borehole through the clay structure, reaming and installing the casing before the clay swells to close the borehole. This is limited in depth due to the practicalities and expense. The casing may remain free or can possibly be cut and retrieved after the borehole is completed.
- Drill through then ream up to and through the dyke and try to position a short length of casing in that zone before it closes. Care must then be taken to insert the drill string through the casing for drilling beyond the zone.
- Branch and drill into the roof or floor strata across the dyke zone. This works on the assumption that most dykes are much thinner in the strata above and below the seam, have created less disturbance to the surrounding strata and present fewer problems.
- Use drilling water additives (muds) which stabilise the clay. Recirculation of the drilling fluid, which is the usual system for using drill muds on surface drilling projects, is not an established practice in underground in-seam drilling. Drill additives can be added continuously but are lost with the waste water, adding substantial cost to the drilling. It can be applied with occasional doses when conditions get "sticky".
- Avoid the zone and access the area beyond the dyke from another area of the mine if possible.

2.7. Flaking mudstone

Some boreholes deflect off the roof strata and continue to final depth. Some mudstones fret with water contact allowing large pieces of stone to drop into the borehole. Individual pieces may be flushed from the borehole but some can lodge in the borehole and either block water flow or jam the drill string when it is being withdrawn. If the surrounding roof or floor strata are suspect, deflecting off these stone intersections should be avoided, with branching being employed to continue drilling.

2.8. High gas content and pressure

In high gas content and pressure environments, most of the previously mentioned unstable environments become more unstable.

Underground drilling does not have the luxury of head of water in the borehole to maintain a constant pressure on the sides of the borehole so all underground drilling is hugely underbalanced as shown in Fig. 1.

Any intersection with unstable coal can result in immediate and rapid ejection of coal particles into the borehole opening in an outburst manner. These events are unpredictable and result in some level of bogging. If flushing circulation can be maintained, the blockage can eventually be cleared. With bigger events, the drill string is bogged and requires an over-coring recovery attempt.

3. Drilling practices

Experience and exposure of the drillers to the characteristics of unstable environments is the key to managing drilling in unstable environments. The driller can then identify unstable zones and their nature and develop means to manage any intersections. From that, early detection of potential blockages and bogging can avoid many bogging events.

Steps developed to identify, manage and avoid bogging include: limiting drilling rates in known unstable areas; rotary/slide (slide one rod-rotate one rod) allows the rotation of the rods to break up larger pieces and also agitate cuttings in the borehole for easier removal; clean out an unstable zone if possible with extended flushing and reaming until stable; drill bits are now supplied with a back-cutting component to enhance the ability to drill back out of boggy ground; and revise the drilling project in line with the limitations created by the environment.

3.1. Drilling additives

The use of drilling additive is restricted in the underground environment without access to settling dams which allow easy recirculation for surface drilling projects. Application is usually through spot situations when "sticky" conditions are encountered. As mentioned earlier, underground drilling does not have the advantage of operating with a static head of drilling fluid in the borehole and recirculated drill "mud" to install a "skin" to the wall of the borehole for stability [9].

The use in the underground environment is usually directed at increasing the density and/or flow rate to enhance removal of cuttings and debris at a rate to avoid blockages.

Some additive applications have been employed with a mixing tank underground. The application is single pass with the additives travelling into and out of the borehole then pumped away with the waste water. This becomes an expensive exercise and is only used in moderation.

4. Over-coring recovery

Experience, developed procedures and suitable equipment have been the key elements to successful over-coring recoveries. PCD bits to 125 mm OD (Fig. 2) have enabled over-coring to greater depths and through stone intersections.

A 150 mm standpipe is installed if areas are prone to instability to avoid having to over-core and replace a 100 mm standpipe before over-coring can commence. Gas problems at the site are difficult to overcome if re-stand piping is required in very gassy situations.

With a bogging event, the borehole depth, magnitude of bends in the borehole and strata penetrated are all assessed to determine the logistics of the operation, and the diameter and make of the shoe bit to provide adequate borehole diameter to reduce in-hole friction. In seams which do not have mining access to eventually recover bogged drill stings, borehole depths are limited to the over-coring capacity of 600 m.

5. Case histories

5.1. Central Colliery-QLD

The German Creek seam at Central Colliery has an inseam shear zone feature which presented very unstable conditions when intersected. Drilling is usually directed above the inseam shear zone and in some cases additional drilling is required under the shear zone. Intersections which are not immediately terminated usually result in bogged rods. Some attempts to drill with a continuous supply of drilling additives had some success at negotiating the shear zone but were generally overly expensive and a hassle to run.

5.2. West Cliff Colliery

Mining at West Cliff Colliery had encountered areas of fractured coal which could not be penetrated with either normal rotary/flushing or directional drilling. Once a borehole collapse began, flushing water compressed the blockage and further bogged the drill string. A system of rotary scroll drilling with BWJ rods fitted with auger scrolls was introduced referring Fig. 3.

Without the benefit of directional control or surveys to correctly position or locate boreholes, this technique was limited to borehole lengths of 90 m. It was used in sequence with short mining distances to allow areas of high gas content to be mined. In recent times, this method has not discontinued with the development of remote mining techniques to mine through areas, and not able to be drilled and/or drained.

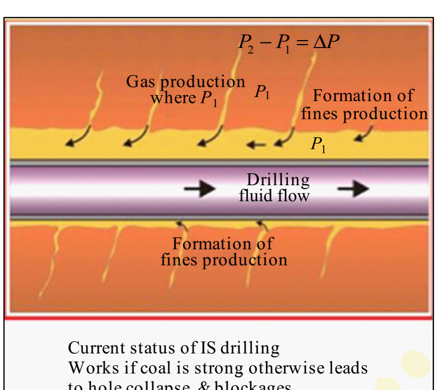

Fig. 1. Underbalanced borehole environment [9].

Fig. 2. 125 mm OD PCD over-core bit.

Fig. 3. Scroll drilling [10].

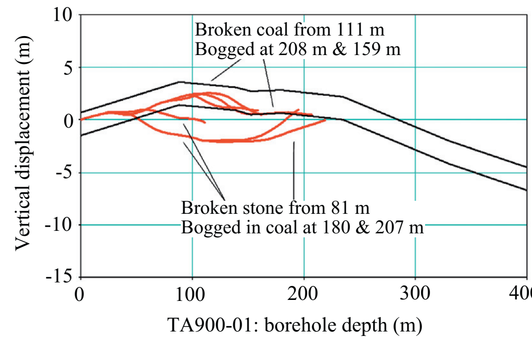

Fig. 5. Profile of unsuccessful boreholes into unstable ground [11].

5.3. Tahmoor 900 Panel

The proposed development of 900 Panel at Tahmoor Colliery was faced with a known area of instability between two defined faults as shown in Fig. 4. Drilling through the area between the faults was expected to be unsuccessful so no gas drainage drilling was likely to be effective in that area. With mining methods in particular shot-fire "grunching" being able to be employed to mine through the unstable zone if not drained the mine required the area beyond to be drained before mining commenced in 900 Panel.

Initial attempts to drill through and under the area proved unsuccessful. Several boreholes were terminated and two drill stings left bogged to be retrieved later by mining as shown in Figs. 5 and 6.

Drilling was then directed up into the strata above the seam and designed to re-enter the seam beyond the zone of instability as shown in Fig. 7. From there, the boreholes were continued out to the final design depth.

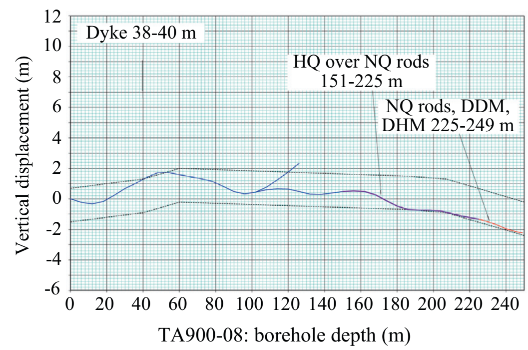

Fig. 6. Profiles of unsuccessful boreholes with bogged drill string and part of overcoring system [11].

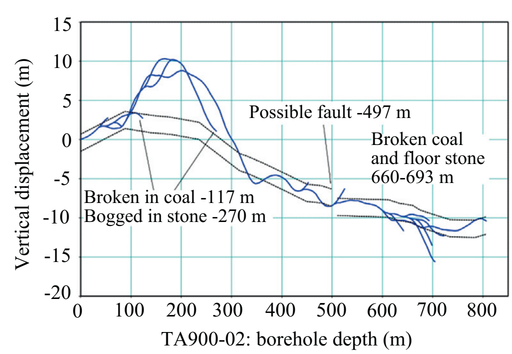

Fig. 7. Profile-profile of boreholes bridging unstable ground [11].

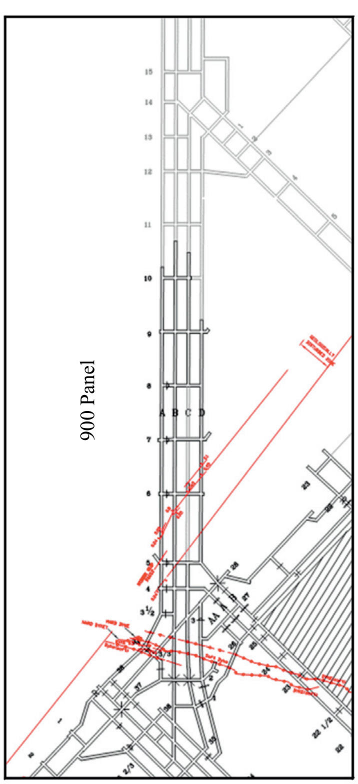

Fig. 4. Proposed development of 900 Panel, Tahmoor Colliery [11].

After some problems, a stable environment was identified 6 m above the seam along which most drilling was directed. The boreholes re-entering the seam had to be designed with a vertical angle to allow them to be maintained within the seam after re-entry. Some instability was encountered at the interface with the seam at re-entry which had to be stabilised with extended flushing and draining before drilling could continue.

The gas content levels through the area of instability between the faults proved to be high and had to be mined by "grunching". The area beyond the faults had successfully been drilled and drained allowing normal continuous miner operations out to the extent of the boreholes as shown in Fig. 8.

5.4. Baijigou Mine, China

Drilling on the project at Baijigou mine in China required negotiating a section of hard, strong stone up to the intersection with

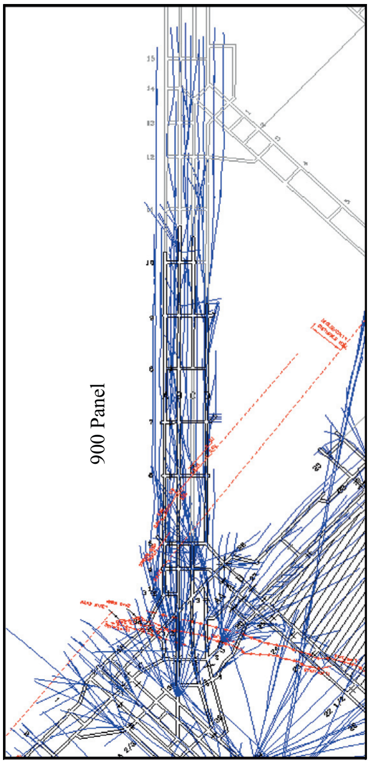

Fig. 8. Completed in-seam gas drainage boreholes [11].

the seam before continuing the drilling in coal out of the final depth (Fig. 9) [12]. The stone section was negotiated using tungsten carbide tipped try turn bits on the Dow, before continuing a hole in coal with a PCD bit. The area of concern was negotiating the interface between the stone in the coal at the floor of the seam. This area was usually unstable and required extended flushing and reaming to stabilise before drilling could continue. Numerous times the drill string became bogged in this area and had to be over-cored with HQ rods to free the drilling.

5.5. Gujarat Wongawilli seam

Drilling at Gujarat was planned from the old workings in the Bulli seam to penetrate into the lower horizons of the Wongawilli seam and continue in-seam for gas drainage (Fig. 10). Prior knowledge identified a one metre thick clay/tuff band in the upper section of the Wongawilli seam which was likely to soften and swell on contact with water.

The plan was to directionally drill through the clay band to the lower section of the Wongawilli seam, ream the borehole to a

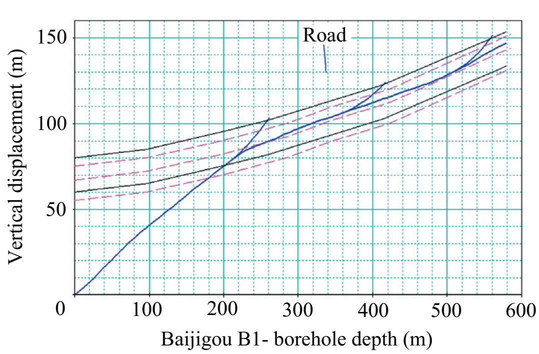

Fig. 9. Baijigou borehole profile [12].

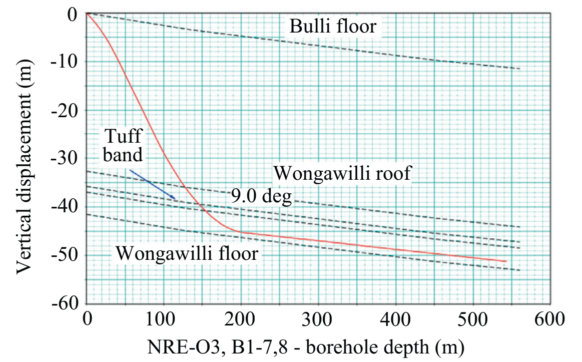

Fig. 10. Cross-measure Wongawilli seam drilling.

larger diameter then install casing through the clay band. The clay section remained open while drilling and reaming but swelled rapidly. The drilling, reaming and installation had to be completed in a 24 h period to be successful. In-seam directional drilling was successfully continued from that point.

This process was improved with the use of a casing advancer, reaming bit which allowed the casing to be used for the reaming with the bit retracted back inside the casing to allow the ongoing drilling. This process removed one of the installation steps and reduced installation and exposure time through the clay band.

5.6. Wuhai-Ping Gou Mine, China

This project involved drilling in both the current seam and cross-measure/in-seam drilling in the lower seam. Boggy conditions were expected so larger diameter standpipes were utilised to allow over-coring if required. Experience was established during drilling in the environment and a set of guidelines were created:

- The drillers followed a set of 6 rules which allowed them to identify and react to the intersection with boggy conditions.
- Problem areas identified from each borehole were extrapolated to the next borehole location to warn drillers of suspect areas.
- Immediate response to bogging was to assess the condition, inform supervisors, maintain drill string integrity and prepare for over-coring.
- Established over-coring equipment, procedure and experienced drillers were required.
- Drilling in the lower seam which would not allow future mining recovery was limited to the over-coring depth capacity (600 m).

Maintaining a file for reference of all recoveries including borehole number, depth of bogging, over-core depth, “success or not”, shifts involved, shoe bit type and diameter.

The cross-measure drilling presented a design challenge. The lower seam proved to have an unstable inter-face at the roof and unstable coal in the lower section. The inter-burden strata were very strong and required a steep angle of intersection to avoid defecting off it. The steep angle was a benefit in limiting contact through the roof interface but made it difficult to curve the borehole up quick enough to avoid the unstable coal in the lower section.

6. Conclusions

(1) When faced with a new environment, past experience is a great asset in managing a drilling project.

(2) Assess the environment before drilling to identify any likely problems.
(3) Develop experience at drilling in and managing adverse environments and have the drillers operating under an established set of rules to identify and assess boggy conditions.
(4) Maintain good communication between drill crews and supervisors.
(5) Progressively update the knowledge gained from boggy ground encounters in one borehole to assess its potential influence on ongoing boreholes.
(6) Develop a risk assessment based procedure for over-core recovery operations.
(7) Establish and maintain a suitable set of over-coring equipment including HQ rods, jaws and guides, subs, shoe bits and stuffing box.

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