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Two Pass Drilling a 6.1 Meter Diameter Ventilation Shaft

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SUMMARY A method is presented for drilling large diameter shafts, for underground mining, in two passes utilizing a conventional raiseboring machine. Special design considerations for the bit body, cutters, stabilizers, and stem will be mentioned.

1 INTRODUCTION

As mines excavate to greater depths, the need for large diameter ventilation shafts is steadily increasing. Labor has become more expensive, causing the mines to utilize mechanized shaft sinking methods to reduce costs, improve safety, and reduce completion time.

Most of the state of the art raiseboring machines which are currently in service do not have the torque and thrust capacities needed to drill the large diameter and depth of shafts needed by the mines. The few machines that are capable of drilling large diameter shafts in one pass are very expensive and require a special drill string to withstand the increased loads. In many cases, the amount of future work prohibits financial justification for the equipment.

This paper presents the special design considerations of the equipment that has successfully drilled a 6.1 metre diameter shaft in broken quartzite. The unstable ground conditions forced changes in the layout of the shaft, special considerations to protect miners while working on the equipment, and modifications in the use and handling of the equipment.

2 SHAFT SINKING METHODS AND EQUIPMENT SELECTION

Deelkraal Gold Mine, which is owned by Gold Fields of South Africa, Ltd. was in need of a 6.1 metre diameter by 600 metre long upcast ventilation shaft. Originally, the mine planned to sink this shaft conventionally by reaming a 2.1 metre center core and slipping the shaft out to 6.1 metres from the top.

Raiseboring the shaft was investigated because completion time was a critical factor. The study indicated that the two-pass drilling method should cut the required time to install the shaft by at least half. As a result, the mine could earn revenue by putting this area of the mine into production sooner.

Another important factor in this decision was safety. Raiseboring has proven to be a much safer operation than the conventional drill and blast method.

Once the decision had been made to raisebore the shaft, it was left up to the contractor, GFC Mining, to select the appropriate equipment to be used with their Robbins 103RM raiseboring machine.

The two-pass raiseboring method was chosen for the following reasons:

- By drilling a 4.2 metre hole and then drilling a second pass to 6.1 metres, the torque and thrust requirements were within the capabilities of their machine.
- The two-pass drilling method would reduce the torque applied to the drill string.
- The bit body had no sophisticated hydraulic equipment which could malfunction.
- They would be able to drill 4.2 as well as 6.1 metre holes in the future.
- Baker Hughes Mining Tools' new BTKC cutter would be used from 2.4 metre diameter outward. This cutter is larger in diameter than most cutters on the market, which reduces peripheral speed and allows for an increase in cutting structure and bearing capacity. These improvements lead to an increase in expected cutter life when drilling large diameters.

3 SITE ESTABLISHMENT AND CONSTRUCTION

The 648 metre upcast ventilation shaft was to be reamed in three equal stages between the following levels.

Level 25 up to Level 19 (2466 to 2250 metres)
Level 19 up to Level 13 (2250 to 2034 metres)
Level 13 up to Level 7 (2034 to 1818 metres)

The three raises will be drilled in the order shown above so that there will be a solid roof above the machine at all times. To accommodate the machine, an 8.0 metre by 8.0 metre by 9.5 metre high excavation was required. The top of the excavation had to be as flat as possible to accommodate collaring of the 6.1 metre diameter bit body.

Because of the size of the excavations and the depth at which they were established, the rock had to be secured with roof bolts. The bit body had to ream into this ground, so fiberglass roof bolts were utilized.

Services that had to be provided were 125 l/s of water for pilot hole drilling and 28 l/s of water for dust suppression during reaming. The machine requires 465 KVA of electricity.

4 SPECIAL DESIGN CONSIDERATIONS

4.1 Long Stem

As the science of raiseboring has developed to drill larger holes, the capacity of the drill string has become a limiting factor. It is useless to have a machine that can supply more torque and thrust than the drill string is capable of withstanding. As the size of the equipment increases, so does the cost. If a large bit body were dropped, a significant amount of damage would be expected. Every effort is made during manufacturing and inspection to make sure that a drill string failure does not occur.

The connection between the stem and the first stabilizer is the most stressed connection in the drill string. The connection is also where the drill pipe has its smallest cross section. Therefore, to reduce bending stresses at the first connection, it is desirable to make the stem as long as possible. The stem designed for this project is over four metres in length. This length was selected because of installation and transportation considerations.

Standard stems are less than two metres in length with .4 metre long wear pads. The longer stem allows for 1.7 metres of wear pads. This significant increase in wear surface, close to the cutters, increases stabilization during collaring.

The stem is equipped with Baker Hughes' patented Taper-Lok System, which allows the stem to be hydraulically removed from the bit body in a short period of time. The removable stem simplifies transportation of the bit body and stem underground. If the stem is damaged, repair time and cost are reduced significantly over stems that are welded in place.

4.2 Machine Torque/Thrust Limitations

The prime contractor and owner of the 103RM raiseboring machine, GFC Mining, had successfully drilled a 4.8 metre diameter by 299 metre raise in quartzite. However, the machine was torque limited, which means the machine would stall before its full thrust capacity could be utilized. An article in the April 1983 issue of Mining Magazine stated the machine is capable of drilling a 3.6 metre diameter by 610 metre long raise.

The machine can supply 450 kNm of torque and 8,000 kN of thrust. The two-stage 6.1 metre diameter bit body has a total of 38 cutters. If the bit body were to be pulled in one pass, the machine could provide a cutter loading in excess of 150 kN per cutter at a depth of 200 metres. Therefore, torque was the primary consideration in determining the diameter of the first stage.

Many formulas have been established over the years to calculate expected torque requirements in various ground conditions. All of these formulas take into consideration empirical factors for rock hardness, drillability, and cutter loading. The following formula was developed based on drilling records from raises that have been done in quartzite in South Africa.

$$(2800 \text{ to } 3200)\ D \times D = \text{Torque (kNm)}$$

D is diameter in metres: and 2800 to 3200 is an empirical factor based on cutter loading.

This is a simplified formula which ignores the number of cutters and their distance from bit centerline. Diameter of the hole being drilled was considered to be the primary factor in predicting expected torque requirements when drilling hard quartzite. In this project, we are torque limited, which leads to the assumption that the same volume of rock should be drilled in the first and second passes.

Based on the preceding formula and using a low cutter loading factor of 2800, the estimated torque requirement for the 4.2 metre stage would be 480 kNm. Estimated torque for the second pass to 6.1 metres would be 530 kNm. Experience has shown that the second pass requires less torque than expected because of rock sluffing.

4.3 Special Stabilization

Two-pass drilling has been done successfully in smaller diametres. These raises have proven that the roller stabilizers which support the bit body during the second raise must be as far as possible from the cutters on the lower stage. Rock sluffing will be expected, which will make stabilizers ineffective if they are too close to the cutters.

The stabilizers should cover a long distance so the bit will follow the first hole as closely as possible. Thirty stabilizer positions were utilized on the first attempt at drilling a 6.1 metre hole in two passes.

The thirty stabilizers are divided into five sets. The two lower sets on the 4.2 metre stage are mounted to an octagon barrel on angled stabilizer wings. Each of the sixteen wings are identical.

If the angled stabilizer wings are mounted in line with each other, they will allow cuttings to flow through. This allows for extra stabilization for the 4.2 metre bit body if needed. If either the upper or lower stabilizer wings are flipped over, as shown in the photo on the following page, the angular distance between the stabilizers will be cut in half. The smaller angular displacement between stabilizers is desired during the second pass, because it will help prevent the bit body from shifting, if a large cavity is formed in the side wall from rock sluffing. Baker Hughes has received a patent for this stabilization concept.

As experience is obtained with this equipment, it is hoped that all thirty stabilizers will not be needed. The requirement for stabilization is highly dependent on rock conditions. If the rock is broken or fractured as it is in our first application, as much stabilization as possible will be utilized.

There will be no stabilization of the drill pipe. Calculations show that stabilizing the drill pipe could actually increase bending stresses in the pipe. The main reason for considering drill pipe stabilization is to prevent the pipe from whipping. The bit body will only turn at 4 RPM; therefore, this is not expected to be a problem.

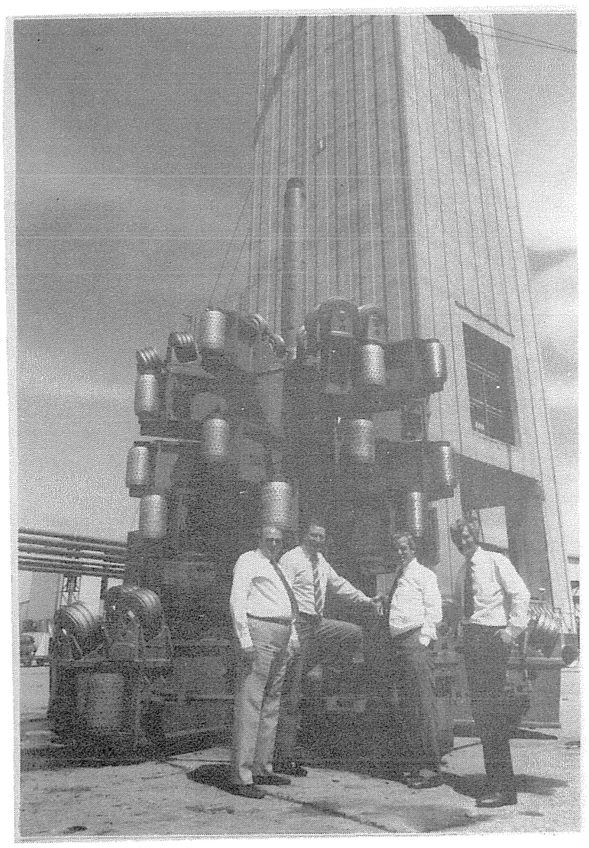
4.4 Size/Weight Limitations

Because the machine has plenty of thrust capability, the primary weight limitation was based on transportation and assembly of the equipment.

The maximum weight allowable for one piece of equipment was 8.2 tonnes. The complete assembly has been estimated to weigh 76 tonnes including cutters and stabilizers.

Size limitations were based on the ability to get the equipment into the hoist cages for transportation underground.

Some of the carts used for transporting the equipment underground were modified so that the components could be bolted in place. This helps protect the equipment and makes it safer for the personnel moving it. Cover plates were utilized to protect contact surfaces and keep tapped holes clean during transportation of the equipment.



The 6.1 metre diameter two-pass raiseboring system was built for GFC Mining to be used at Deelkraal Gold Mine near Carltonville in The Republic of South Africa. From left: Mr. Deon Joubert, Divisional Manager, Mechanical Mining; Ron Simons, Chief Engineer; Frank Guise-Brcwn, Managing Director, all GFC Mining; Willie Nortje, Planning Officer, Deelkraal Gold Mines.

4.5 Inspection of Stabilizer and Cutter Locations

Location of cutters and stabilizers is important. If one stabilizer is further from bit centerline than the rest, it will be loaded more heavily and wear faster.

All sixteen of the angled stabilizer wings were manufactured identically. The wings were installed on the stabilizer extension and centered on a large milling machine. Runout was checked to make sure each component was manufactured properly.

Each of the five rows of stabilizers were positioned beyond the center line of the outer kerf on the gauge cutters. This would induce a cutting action by the stabilizers for maximum stability. This could also cause an increase in torque and increased wear on the stabilizers. Because of this possibility spacers were provided between the stabilizer pillow blocks and the stabilizer wings. By manufacturing different thickness of spacers, the 5 sets of stabilizers can be located in a variety of combinations. This will allow for optimization of stabilization, torque requirement, and stabilizer life, depending on the ground conditions being drilled.

4.6 Wing Installation and Support

Because of size limitations, the bit body consists of 34 separate components which require a large number of bolts to assemble. The bolts which attached the wings will be subjected to much higher loads than experienced on smaller bit bodies. A great deal of testing was conducted to verify that the bolt assemblies would be installed properly.

Bolt manufacturers state the pre-load can be up to 90 percent of yield strength without failing the bolts during normal service. A ratcheting torque wrench was used in combination with a torque multiplier to make sure each bolt was properly pre-loaded.

The wings were manufactured from mild steel plate. Testing showed that if the specified pre-load was induced into the bolts, the bolt would compressively yield the mild steel. Special washers were manufactured to disperse the load over a larger area.

The wings extend out significantly further than any wings previously supplied by Baker Hughes. Even with the precautions taken during bolt installation, it was decided that the wings needed additional support. Heavy duty turnbuckles which are manufactured from high strength steel are positioned between adjacent wings to act as support struts.

5 PROBLEMS ENCOUNTERED IN MANUFACTURE AND USE

5.1 Damage of Stage Bolt Plates

Prior to installing the cover plates on the bottom of the bit body and the top of the stabilizer extension, riggers used the torque pin holes for hoisting. The torque pins are provided to transmit torque from one stage to another. Because the holes were damaged, the components had to be returned to the machine shop so the holes could be enlarged for new torque pins.

This added expense magnifies the need for numerous lifting points for easy handling of the equipment.

5.2 Special Rigging

The rock in the area where the bit body was assembled was unstable and fractured. This made it unsafe to use roof bolts in the hanging wall for hoisting of equipment. An I-beam was mounted between the stem and the sidewall. A lifting hoist was mounted on rollers so that the wings, cutters, and stabilizers could be easily lifted and rolled into position. The same I-beam was used for installing the Taper-Lok stem into the base bit body.

5.3 30 mm and 60 mm Kerf Spacing

The kerfed cutters used on this project are designed to create either a 30 mm or 60 mm kerf spacing. To create a 30 mm kerf spacing, cutters with dissimilar kerf spacing are located opposite each other. To create a 60 mm kerf spacing, identical cutters are located opposite each other.

Geological reports indicated that a seam of dyke was running at an angle away from the bottom of the vertical shaft. Dyke was proven to be difficult to drill so the bit body was initially dressed for 30 mm kerf spacing. After drilling 50 metres, the bit body was lowered because of loss of penetration.

The rock being drilled was very fractured and unstable causing the bit body to run rough. A few of the cutters had to be replaced because of shattered carbide. When the bit body was put back into service, it could still not establish an acceptable penetration rate because of rough drilling. The bit body was lowered again. There was an increase in the amount of fines, indicating that the drilling conditions had changed. Geological reports indicated that the remainder of the hole would be glassy quartzite. Lab testing has shown that the glassy quartzite has an unconfined compressive stength of 170 mpa. New cutters were put on the bit body to establish a 60 mm kerf spacing.

Because of the rough running, the upper stabilizer wings were installed. These two changes proved to be effective. The bit body still ran rough, but penetration rates of 10 to 13 mm/min. were maintained.

The cutters could only be loaded to 90 kN per cutter. When loading was increased, the drilling face would breakup causing the machine to stall.

5.4 Packing of the Bit Body

The stabilizer wings which were added after drilling 50 metres eventually led to a major packing problem. After drilling another 100 metres, the bit body lost penetration. The bit body was lowered and found to be completely compacted. Large boulders fell from the cutting face and be came trapped between the cutter wings and the stabilizer wings. The cutter mounts on the main bit body are positioned on .23 metre high riser blocks to improve chip removal. Even with this precaution the large boulders trapped enough rock to bury the cutters in the inner positions. Once the cutters become buried in cuttings, fines are created which force their way past the seals, which causes premature bearing failure.

The stabilizer wings were removed and the bit body was put back into service. The 4.2 metre assembly performed very well, but after reaming another 50 metres, the bit body again lost penetration.

The bit body was lowered and again found to be completely compacted. This time large boulders had become trapped between the support struts and the bit body, creating a dam for smaller cuttings.

5.5 Canopy for Protection (First Raise)

Drilling an entire raise without lowering the bit body is ideal. Unfortunately, it is sometimes necessary to work on the bit body after part of a hole has been drilled. The boulders which led to packing problems on the bit body also caused great concern for the miners' safety when servicing the equipment. The mine's safety engineers required that a canopy be in place over the bit body before anyone was allowed below the open hole.

The first canopy that was tried consisted of four large pipes that were positioned in a square and chained to roof bolts. Large pieces of timber were laid on top of the pipes to close off the 4.2 metre hole. A large boulder fell and bent one of the pipes which allowed some of the timbers to dislodge.

The second canopy tried was a large steel frame structure that was supported internally by large wood beams. The steel frame had a slot in it so that it could fit around the stem. The canopy was then hoisted into position and chained to roof bolts. The slot in the frame was then closed off by laying timbers across the slot. This canopy was also damaged when a large boulder fell. The chains which were holding the canopy in place broke. The second canopy was hoisted back into position. Adjustable support struts were positioned on each corner of the canopy so the canopy could be supported from the ground as well as from the chains.

5.6 Delays in Operation Because of Cleaning

The mine used an air-operated rocker shovel for removing the cuttings. The shovel ran on the same tracks as the ore cars. Early in the program it was found that one rocker shovel could not handle the amount of cuttings being drilled with the 4.2 metre bit body. With a penetration rate of 12 mm/min., the bit body would drill 9.7 cubic metres of rock per hour (25 tonnes per hour).

Drilling had to be stopped on several occasions to allow the shovel operators to catch-up. With this size of hole, it would be too dangerous to allow the hole to fill up. If the hole became packed with cuttings, a rockslide could result when the cuttings were dislodged. If water were trapped above the cuttings, the whole lower level could be flooded.

5.7 Change in Shaft Layout

Geologists felt that the unstable ground conditions which resulted in large boulders falling from the sides of the 4.2 metre hole were caused by the seam of dyke that runs at an angle away from the bottom of the shaft. By the time the first 4.2 metre raise was completed, 40 to 50 percent of the sidewall had fractured away. Because such a large portion of the hole was missing, it was decided that there would not be enough stabilization to collar the 4.2 to 6.1 metre stage.

Two different canopies have been dislodged because of falling rock. There is concern that this will be an even greater problem with a 6.1 metre open hole. Safety was a primary consideration when deciding to raisebore these holes. The mine did not want to take a chance that someone would get seriously injured when trying to remove the 6.1 metre bit body.

The upper two raises will still be reamed to 6.1 metre diameter. Two 2.1 metre diameter holes will be drilled next to the 4.2 metre hole on the lower section. Blowers will be used to make up the difference in air flow through the smaller diameter holes.

Because the dyke is further away from the glassy quartzite in the upper two holes, it is believed that the fracture zone will not be as severe. Pilot hole drilling tends to support this theory. Pilot hole bit life was twice as great in the upper two holes as it was in the bottom hole.

5.8 Canopy for Protection (Second Raise)

Because of the problems encountered during the first raise, the mine's engineers designed a heavy duty support structure manufactured from I-beams to support the canopy for the second raise. The canopy had a slot cut in one section so that it could fit around the drill string.

The two sections of the canopy were mounted on rollers so that they could be rolled back on top of each other, below the hanging wall, when the bit was drilling. This canopy worked very well to protect the miners when they were assembling the bit body. When drilling commenced, the shovel operators were again unable to keep up with the drilling. The support structure was not adequately tied to the side wall. When the support structure became buried in cuttings, it could not withstand the weight and impact of the falling rock and was severely distorted.

5.9 Results to Date (Second Raise)

The ground conditions on the second raise did prove to be more stable than the first raise. However, there was still a great deal of rock sluffing from the sidewall. After drilling 75 metres of the 4.2 metre hole, 20 to 30 percent of the sidewall had fractured away. There was concern that there would not be enough stabilization if the 4.2 metre raise was completed prior to collaring the 6.1 metre stage. By collaring the lower stage with 125 metres of the 4.2 metre hole still not reamed, a majority of the drill pipe would be supported by the pilot hole.

The collaring of the 6.1 metre stage went extremely well. After three hours of collaring the lower stage had reamed a full face. At this time, full load was applied. 70 metres of 6.1 metre diameter hole were reamed in ten working days with no problems. The machine was torque limited, but because the stabilizers were cutting rock, the 4.2 to 6.1 metre stage ran smoother than the 4.2 metre stage. The amp metre did not fluctuate as much during the second pass. However, when the drilling face broke away, the machine did stall on occasion. In unstable rock, it took up to 8.5 hours to drill one 1.5 metre long drill rod. The shortest time to drill 1.5 metres was 1.8 hours.

The second pass was expected to require more torque than the first pass. The effects of rock sluffing and the amount of torque required by the cutting stabilizers is unknown. The average penetration rate for the 4.2 metre stage was 8.1 mm/min.. The average penetration rate for the 6.1 metre stage was 7.3 mm/min.. This represents a 10.0 percent reduction in penetration rate.

Once the 4.2 to 6.1 metre stage had successfully reamed 70 metres of the second pass, the lower stage was removed. The 4.2 bit body was put back into service and reamed an additional 50 metres at which time the first stabilizer failed, allowing the bit body to fall 125 metres. The base head was distorted and required replacement. Modifications were made to the base head to improve cutting removal.

The new 4.2 metre design was put back into service and successfully drilled the remainder of the 200 metre long raise. As of mid-April, 1988, the 4.2 to 6.1 metre stage had reamed an additional 65 metres, or a total of 140 metres of 200 metre long raise.

6.0 CONCLUSIONS

The rock conditions have limited the success of the two-pass drilling system. The fact that these severe conditions have been overcome indicates that with proper planning almost any rock can be drilled using this concept.

The two-pass drilling method creates the opportunity for operators to ream 40 to 50 percent larger diameter shafts with equipment they currently own. This method will be quicker and safer than conventional shaft sinking methods. The investment cost of this bit body is significantly less expensive than purchasing a larger raiseboring machine and a new string of drill pipe.

7.0 ACKNOWLEDGEMENTS

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8.0 REFERENCES

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