Method of Developing and Equipping a 21st Century Haulage at Depth

JD SPIES
General Manager, (Moab Khotsong Mine)

A BLOM
Section Manager, (Moab Khotsong Mine)

SYNOPSIS

This paper describes the methodology and design of tunneling at depth of the Moab Khotsong project. It deals more in depth with the innovative excavation techniques and tunneling standards employed whilst developing through weak MB 10 quartzites in order to access the orebody safely.

INTRODUCTION

The Moab Khotsong project forms part of AngloGold Vaal River Operations. The operation in addition to the project consists of three other production mines situated near Klerksdorp in the North West Province (see Locality Plan – Figure 1). Following the successful exploration of the down dip extension of the Vaal Reef, situated to the south of the Great Noligwa Mine, it was decided to exploit the orebody.

The orebody lies at depths between 2 000m and 3 800m below surface with only limited quantities of ore lying above 2 300m. The geological structure is complex and highly faulted with large fault loss areas. Due to the size of shaft pillars, as well as the fact that they cannot provide the necessary protection against rock pressures at depth, it was decided to site the new shaft in Great Noligwa’s lease area. This provided the opportunity of extracting the shaft pillar before the shaft was excavated and equipped but required the development of long access tunnels to reef. The main surface shaft and sub – vertical has been sunk and equipped down to a depth of 2 300m and 3 164m respectively (see Shaft Layout – Figure 2 & 3).

The infrastructure and the access development on the first two levels will be excavated by means of a mid shaft loading system. Inter level spacing on these levels are 300m apart, and this decision was taken in order to reduce access development meters to the reef blocks which are 2 500m away. A mid shaft loading system which consists of a single skip / cage combination with a 1 000 ton/day hoisting capacity, limits the volume of development that can be excavated and serviced.

GEOLOGICAL INFORMATION

The upper levels are situated in the Commonage Formation, which is a fairly monotonous quartzite with scattered white grains. The bedding thickness can vary up to 135 cm with intermittent thin shale bands that could cause stability problems (avg. U.C.S.: 121 – 235 MPa). Abundant small scale faulting is present as well as associated joints giving the rock formation a fractured appearance. Major faults are also present with numerous sill and dyke intersections.
TUNNELING

Strategy

Definite tunneling strategies had to be formulated for Moab Khotsong as current mining methods cannot simply be extended to deep level mines without compromising safety and would require significant modifications to standards, work practices and mine design. During station development on the main shaft it became apparent that because of poor ground conditions, conventional methods of tunneling would not suffice on Moab Khotsong Mine where greater depths are anticipated. This therefore necessitated that certain principal decisions be made that will ensure safety, be practical and cost effective. In addition these decisions should be aligned with the horizontal transport vision of a 21st century mine. The principal decisions and any subsequent decisions taken will be discussed in detail under each aspect of tunneling.

Mine Design

The decision was taken to develop a main haulage and return airway with connecting crosscuts 100m apart on the two levels serviced by the mid shaft loading system because of the hoisting constraint (see Figure 4). This limited the planned rate of advance to 180m per level per month (see Production Profile).
Equipment Selection

From a workshop involving Technical Development Services it was decided to use handheld jackhammers due to the length of round and support requirements in conjunction with LHD’s. Tunneling commenced in August 1998 with jackhammers and diesel driven LHD’s in order to complete all the infrastructure development around the shaft barrel. Subsequently the necessary infrastructure was installed to accommodate track – bound equipment to follow 100m behind the access development with electro – hydraulic LHD’s tipping directly into hoppers at established tipping points.
Mining Cycle

From the outset it was envisaged that 3 crews would be required to work 12 hour shifts. The main reason behind this decision was to balance the mining cycle and to ensure that each crew could be held accountable for the work required per shift. This required each crew to blast, clean and fully support 2 ends per shift including the wetcreting of these ends (see Figure 5). Working 12 hour shifts also reduced man traveling time in the shaft, thereby increasing rock and material hoisting available time.

![Figure 5](image)

Tunnel Dimensions

The size and number of access tunnels in all future deep level mines will mainly depend on ventilation requirements, such as system pressure losses and acceptable air velocities. This was also relevant for the Moab project with an area requirement of 16m² per tunnel, which equates to an end 4.4m high x 4.5m wide (see Figure 6).

Tunnel Profiles

FLAC 3D computer modeling done by ITASCA was used to obtain the optimum tunnel profile. Aspects considered for the various layouts were:

- The optimum shape of the tunnel in quartzite and shales;
- Support requirements for the optimum shape under virgin stress;
- The peak loading sustainable by each support system.
A stress value corresponding to a virgin stress value for a depth of 2,850 m below surface (93 Level) was used in the modeling. For the five different profiles modeled, rectangular, circular, elliptical, elliptically arched and circular arched, the ellipse with a width to height ratio of 1.3 was found to be most favorable profile. For practical reasons the elliptically arched profile was therefore adopted (see Figure 6).

![Figure 6](image_url)

**Figure 6**

![4.4 x 4.5 Tunnel](image_url)
Breaking

Due to the fractured nature of the ground, the decision was made to limit the length of the blast holes to 2.5m maximum. This eliminated the use of drill rigs both for utilization purposes as well as cost effectiveness. Protecting machine operators from this environment will be discussed under support. Due to the size of the required ends, breakaways and holing positions were identified as potential high risk areas and certain well defined action steps have been put into place to counter this (see the following).

Holings

Whenever two excavations come to within 20m of holing into one another, one of the ends shall be stopped. This end will then be examined for misfires and shall have the primary support installed to within 1m from the face position, with wetcrete being applied right up to the face on both side-walls and hanging-wall (see Sketch 1).

破壊

由于地面的断裂性质，决定将炮孔长度限制在2.5米以内。这消除了钻孔机的使用，无论是从利用目的还是成本效益。保护机器操作者免受这种环境的影响将在支持部分中讨论。由于所需端口的尺寸，破口和穿孔位置被确定为潜在的高风险区域，并且已经制定了某些明确的行动步骤来应对这种情况（见下面）。

穿孔

每当两个开挖面之间距离小于20m，其中一个面应当停止。这个端口将被检查是否有哑炮，并将在距脸面1m处安装主要支持，湿喷混凝土将被直接喷射到脸面上，两侧壁和悬挂壁上（见图1）。

![Sketch 1](image)

Breakaways

All breakaways are blasted according to a specific sequence in order to ensure that minimal blasting fractures are induced at bull-nose positions (see Sketch 2).
**Underhand Development Faces**

Due to frequent strain bursting occurring on the development faces, decisions were taken to carry all the faces underhand. This would provide some means of protection for the workers in that the rock if dislodged would slide down the face and not fall over.

**Charging Up and Blast Initiation**

Smooth-wall blasting is done using conventional cartridge explosives to charge up the perimeter holes, and ammonium nitrate based explosives are used on the remaining holes. Conventional fuse and igniter cord is used in conjunction with the above mentioned explosives. The blast is initiated by means of battery operated shot exploders from a safe designated blasting point.

Trails conducted with shock tubes over the last three months on one particular level, not only improved the face advance from 1.7m to 2.2m per blast but also reduced the explosive accessories cost by R67 per meter. It is envisaged that when the trails have been concluded all development will then utilize shock tubes.

**Support**

The depth at which tunneling is taking place has a significant effect on the ground conditions. Strain bursting which is the sudden release of stored strain energy, close to the face, occurs frequently when bedding planes with a width of > 1.2m are exposed. The mechanism of failure is the buckling of the thin slabs created when large bedding planes are exposed (see Photo 1). The high vertical stress which acts on the thin slab cause it to buckle inwards and results in the sudden release of the strain energy. Counter measures employed, are de-stressing the face and installing additional support into the > 1.2m bedding planes.
On three occasions large rocks (± 2 tons) were ejected into the excavations, and this necessitated that the principal decision was made to protect the drilling crews by means of installing wire mesh on the face, unsupported hanging and sidewall areas.

![Photo 1](image1)

*By adding construction lines the bulging of the upper sidewall becomes more evident.*

![Photo 2](image2)

*Photo showing strain bursting*
By means of a vigorous safety campaign “NO ROCK WILL FALL UNCONTROLLED”, fall of
ground accidents were reduced to such extend that no fatal accident has occurred in the last
27 months. The following table illustrates to what extent fall of ground accidents have been reduced.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>DRESSINGS</td>
<td>77</td>
<td>29</td>
<td>32</td>
<td>2</td>
<td>6</td>
</tr>
<tr>
<td>L.T.I.</td>
<td>41</td>
<td>16</td>
<td>9</td>
<td>10</td>
<td>6</td>
</tr>
<tr>
<td>S.I.F.R.</td>
<td>25</td>
<td>12</td>
<td>6</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>EVENTS</td>
<td>118</td>
<td>45</td>
<td>41</td>
<td>12</td>
<td>12</td>
</tr>
</tbody>
</table>

Note the events include L.T.I. as well as dressing cases.

Making Safe

The Miner will on his initial examination of each working end after barring has been done, demarcate any geological intrusions with yellow paint. This will serve as his personal signature to indicate to his workers that he has personally examined the working place.

Temporary Support

This consists of wire-mesh on the unsupported hanging and side-walls secured by means of “Spies props” and split-sets. The “Spies prop” consists of a 1,5m length of 200mm pipe with a base plate welded onto it. Suitable slots are cut into the side of the pipe to accommodate the control valve of a 20 ton hydraulic prop inserted into the pipe. A suitable length of 150mm mining pole is then inserted into the pipe on top of the hydraulic prop is then remotely pressurized to support the mesh against the hanging-wall (see Sketch 3). The main reason for using these props is that because of the height of the excavations no suitable mechanical props are available on the market that can give the required support resistance of 20 tons.

Permanent Support

Due to the fact that wetcrete is carried 12m behind the advancing faces to accommodate the mining cycle, primary as well as secondary support consisting mainly of 2,9m grouted rockstuds are installed simultaneously on the advancing faces (see Sketch 4). Quality grouting is of paramount importance when installing rockstuds and long anchors in deep level mines. Specific members of each crew are responsible for grouting of support holes. They have been fully trained in all aspects of grouting, and this enables supervisors to hold specific crew members accountable for quality work.
The need for rock engineering training for Moab Khotsong employees was identified some time back, as most of the employees had no previous deep level mining experience. All supervisors therefore had to attend a formal accredited training course. In addition to this an informal “in house” training course was compiled by the Moab Rock Engineering Department, which was based on actual accident investigations and local modes of rock failure which was presented to all employees.
employees (see Examples 1 – 3). The training also included standards and basic strata control principals. These standards are dynamic and are updated as new experiences are gained, as we are pioneering development and sinking in the Klerksdorp area at depths beyond 3 km and cannot gain any experience from any adjacent mine.

In order to emphasize and create understanding a “Rock Engineering Zero Tolerance Board” incorporating much of the material used in the informal course is displayed at all waiting places underground. Models of major geological intersections are also made to create understanding and to plan the sequence of events in order to traverse the intersection safely.

Example 1

![Preventing Strain Bursting of Side Walls](image1)

**Preventing Strain Bursting of Side Walls**
- Large potential for strain bursting
- Zone of high stress adjacent to face
- Pre-conditioning holes move zone of high stress further into the solid
- Blast holes

Example 2

![Preventing Strain Bursting of Face](image2)

**Preventing Strain Bursting of Face**
- Identify beds greater than 1.2 m thick
- Always work under mesh canopy
- Always work under mesh canopy
- Pre-conditioning holes

Front View Showing Position of Pre-Conditioning Holes Alternate Positions Every Day

**Hole spacing and blast design**
Example 3

Wetcrete

Strain bursting and rapid deterioration of exposed rock surfaces due to high stress in conjunction with the dilation of the rock, necessitated the rapid application of wetcrete in current static conditions as close to the advancing faces as possible. It is anticipated that the current wetcrete application would suffice in the long-term stability of the access tunnels, and that the need for meshing and lacing would not be necessary in rehabilitating these excavations in future. This would be both cost effective and in line with the vision of creating maintenance free access tunnels.

In view of the above decision an underground batch plant which is electronically controlled was installed on an upper level (see Sketch 5). This batch plant can supply wetcrete to all the development done on the sub-vertical shaft. The wetcrete is supplied via concrete columns installed in the shaft barrel to the various levels (see Sketch 6).

The supply and demand for wetcrete is done via a voice recorded communication system to ensure the timeous delivery of wetcrete to the respective levels. On levels equipped with tracks a trackbound agi-car and loco collects the wetcrete at the station and transports it to the required area. On trackless levels LHD’s with a receiver bin placed in the bucket (see Photo 2) is used to transport the wetcrete to the required area. The wetcrete is then tipped directly into the receiver bin of a high volume concrete pump and then sprayed onto the rock face. Currently the pump is transported by the LHD to the specific end that needs to be sprayed and this leads to the disruption of cleaning and drilling cycles. These pumps are costly and are easily damaged by transportation. Therefore on one specific level the pump has now been installed in a semi-permanent position to service both ends via pump columns up to a distance of 300m, and is moved forward as the need arises. The main advantage of this installation is that it is now totally divorced from any other mining activity, and spraying can now take place as and when required.
Wetcrete is applied to within 12m meters from the face after the blast to coincide with the ventilation standard. Dedicated trained crews apply the shotcrete to the rock faces. The rock face is barred, properly washed down and all rock-studs are re-tensioned and cut off so that only 100mm protrude from the rock. This then serves as a thickness indicator that must protrude 50mm when spraying is completed.

**Cleaning**

Heat generation from diesel driven LHD’s at depth necessitated the introduction of Electro Hydraulic LHD’s to clean the access development. Tipping points are established in the connecting crosscuts that are always within 100m from the face. Tipping takes place directly into 8 ton bottom discharge hoppers pulled by 8 ton battery loco’s (see Sketch 7).

The two levels developed by means of the mid-shaft loading system are critical for the establishment of ore reserves. To eliminate any cleaning delays because of scaling due to dog-earing (see Photo 3) of ore-passes they were supported, and Moab designed wearing blocks were installed in tap-passes. The vertical ore-passes were supported by means of grouted loops and shotcrete. The Moab wearing blocks consists of Andesite based concrete blocks and Manganese grizzly bars cast into slots blasted into the foot-wall of the tap-pass at 4.5m intervals. These blocks have been very successful to date, and have created “dead boxes” on the foot-wall of the tap-passes thereby eliminating any further scaling (see Sketch 8).

**Ventilation**

The twin ends are ventilated with a minimum of 0.3m³/s/m² face area by means of 760mm diameter force columns only, with all the connecting crosscuts sliped at 45 degree angles to accommodate the columns within the tipping points (see Sketch 9). Re-entry periods of 30 minutes are maintained. Closed loop high -pressure cooling cars are installed in connecting crosscuts and are moved forward as required. These cooling cars ensure an available air temperature of 23.5°C wb at the inlet of the force fans.
Sketch 7

Photo 3
Construction

Pipe Suspension

Temporary pipe columns consisting of 100mm compressed air, 50mm service water and 50mm pump columns are suspended at 4.5m intervals next to the ventilation columns by means of eyebolts, chain and ‘S’ hooks.

Permanent pipes consisting of compressed air, service water, drinking water, pump and chilled water columns will be suspended on vertical steel bearer sets concreted into the foot-wall.
**Rail Construction**

Semi permanent tracks will be installed 1.6m below grade during the development phase in a dedicated tramming haulage. The reason for this is that with the limited shaft time available, ballast cannot be provided to grade the tracks to the final elevation of 1.5m below grade, this can only be done when deepening of the main shaft is completed. Tracks with an A class rating will be installed consisting of 30kg rails on 10 ton axle load concrete sleepers with thermal welded joints. In order to ensure low maintenance on the track installations, drains will be installed 2.1m below grade and satellite pump stations will be installed to ensure that no mine water comes into contact with the ballast rock. The top elevation of the temporary roadway is of critical importance for track and drain installations. The step by step sequence of track installation is shown in sketch 9.

---

**Cover Drilling**

The length of the cover holes have been increased from 120m to 150m, in order to synchronize the rate of advance of the ends to that of the site preparation and drilling time required for each hole. To ensure that the ends are always in 20m of cover, instructions and the required sequence of events are detailed in sketch 10. The purpose of the cover holes is threefold, to provide early warning of flammable gas and secondly to identify high stress areas in the vicinity of geological intrusions by means of core sampling. Thirdly to verify geological information obtained through the 3D seismic survey in order to site tunnels in the best possible position relative to the reef (see Sketch 11).
COVER DRILLING OF 150M LENGTH HOLES

IN ORDER TO ENSURE ENDS ARE ALWAYS WITHIN COVER WITH A 20M OVERLAP THE FOLLOWING PROCEDURE NEEDS TO BE FOLLOWED

- ESTABLISH CUBBY 20M PAST THE LAST CON. X/C IN THE RAW
- CLEAN AND SUPPORT CUBBY TO MINE STANDARD
- ADVANCE RAW 6M PAST CUBBY POSITION
- DAY 1 RIG DIAMOND DRILL MACHINE AND DRILL AND INSTALL CASING PIPE, ADVANCE RAW 4M / DAY
- DAY 2 ONWARDS DRILL COVER HOLE 10M / DAY AND ADVANCE RAW AT 4M / DAY

Sketch 10

GEOLOGY 95 LEVEL

MULTIPLE ENDS

UCS = Uniaxial Compressive Strength

Sketch 11
Water Handling

Water control in any tunneling operation is of the utmost importance, therefore proper handling facilities must be provided at all times. Roadways must be kept dry to minimize tyre wear on trackless vehicles. Use is made of air driven portable pumps installed in all tunneling faces, from where the water is pumped via pipe columns to a vertical pump installation. From this position it is pumped via a satellite pump station to the dams situated at the station.

**WATER HANDLING**

NOTE: PERMANENT PUMP INSTALLATIONS WILL BE LEAP-FROGGED AS SOON AS CONNECTING X/C HAS HOLED.

![Diagram of Water Handling](image)

Sketch 12

**MANAGEMENT REVIEW PROCESSES**

**Safety Campaigns**

Various safety campaigns are vigorously management driven in all aspects of the Moab project, and are revived from time to time as the needs are identified. Examples of some of these campaigns are listed below and are self-explanatory:

- No rock will fall uncontrolled;
- No equipment or material will be handled un-aided;
- No job is so important that it cannot be done safely;
- Do it right the first time;
- I will make a difference and collectively we will make a success;
- Every person has the right to a healthy retirement.
**Induction**

Moab mine being a project with various phases of work that has to be performed, and when these phases change induction of all employees is of paramount importance to ensure that the work is carried out safety, on time and within budget. For this reason all the mid shaft development crews were fully inducted in all aspects of tunneling as described in this paper. Supervisors were subjected to a written examination of the relevant required standards of work.

**Progress Control**

Weekly progress meetings are held to monitor specific requirements for the project to ensure that no delays are caused by inadequate planning, infrastructure or late ordering of equipment.

Monthly pre-planning meetings concentrate more on the work required for the forthcoming month to meet the set targets, as well as any foreseen requirements or obstacles that can impede progress.

Scrutiny sessions held monthly reviews the performance of each aspect of the project. Detailed analysis of safety statistics, production achievements and costs are scrutinized and corrective action implemented where required.

**Quality Control**

Quality Controllers working directly under the supervision of the Rock Engineering Department, conduct regular inspections on the quality of grouted support installations and the application of wetcrete on the rock faces. The support as well as the application of the wetcrete is done by outside contractors. The Quality Controllers must inspect and verify the quality of the work done during a measuring month before payment can be made. This ensures that any sub-standard work can be identified and rectified during the measuring month. Histograms of all the audits are compiled during each month and presented to Management for identification of the critical few and to take the necessary action.

Some examples of the histograms are included (see Support Histograms overleaf).
CONCLUSION

Safety

Considerable success has been achieved in safety through the continuous commitment of management and all employees, as well as the dynamic standards and work practices employed to eliminate incidents. For the first time in mining history a sinking project achieved a million fatality free shifts. In addition to this achievement the Anglogold Chairman’s Shield was won for the last three consecutive years for the best improvement on the previous year’s Serious Injury Frequency Rate.

Management realizes that the commitment to eliminate all injuries is a journey and not a destination, and would therefore require dynamic standards and work practices as well as continuous awareness and mindset campaigns.

Project Progress

With the initial planning of the production buildup, consideration was given to all the different aspects of the tunneling operation. As most of the production crews were inexperienced in this type of mining, a conservative target was set for the first few months which catered for a learning phase in all aspects of the required work. As experience was gained targets were gradually increased and achieved by the crews, and the tunneling project is now on schedule.

The main aim of the tunneling project was to deliver a quality developed meter that was aligned with the 21st century haulage, in that no maintenance would be required to both the excavation as well as the infrastructure installed.

ACKNOWLEDGEMENTS

The authors would like to thank Anglogold for their permission to publish this paper.