SHAFT SINKING METHODS BASED ON THE TOWNLANDS ORE REPLACEMENT PROJECT – RAISEBORING.

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1. Synopsis

This paper is based on the Townlands Ore Replacement Project whereby the concept of conventional sinking of one large diameter shaft was declined and replaced with three smaller raise bored shafts. A wire line geophysical survey was done and the results indicated that a single shaft larger then 4 m diameter unsupported would not be suitable. The shafts were placed 28 meters apart measured from centre to centre. To ensure that the skin to skin pillars between the shafts remained regular and to minimise any deflection, the pilot holes were drilled with the Rotary Vertical Drilling System. The different shaft sinking methodologies are discussed explaining the risk associated with each method.

2. Introduction

A trade-off study by using the Anglo Platinum Turnbull risk assessment covered the comparison between the different methods to sink the ventilation shaft. This risk assessment was conducted in the concept phase to obtain the required ventilation requirements as determined by the Ventilation Engineers. That was:

- A single raisebore hole of 6,7m diameter which will be fully supported resulting in a final internal diameter of 6,5m;
- Three by 3,8m diameter raise bore holes that will be unsupported;
- A single 2,4m diameter raisebore hole that will be sliped and lined to a final diameter of 6,5m; and
- Conventionally sunk shaft of 6,7m diameter to a final lined diameter of 6,5m.

The following significant high risk issues were identified in the risk assessment:

- Timing: EMPR amendment approval for blasting on surface;
- Fall of Ground and Fall of Men in the excavation;
- Raisebore chip handling using the existing shaft infrastructure; and
- Water handling underground

The trade-off showed that although the blind sink option had a competitive risk rating, the time that it would take to be fully operational would negatively affect the current and future production areas of Townlands Shaft, as well as significantly increase the safety, health and environmental risk to employees.
Table 1 shows a summary of the key decision criteria that resulted in the recommendation.

Table 1

Area	Decisive Factor	Results	Decision
Financial	Lowest capital cost Lowest operating cost	The 3 raise bore option had the least capital requirement.	Including the provision for support cost – 3 raise bore option remains at the least capital requirement.
Strategy	Shaft sinking timeously completed	The 3 raise bore option will be the quickest.	The 3 raise bore option will be completed sooner than the other options.
Legal and Environmental	EMPR timing, surface building survey	May take long for blasting option; Non-approval of EMPR.	The 3 raise bore option will be completed sooner than the other options.
Technical	Water, support, deflection, pillar extraction, chip handling, etc.	See below.	3 Raise bore option preferred.
SHE	Lowest risk to health and safety		The 3 raise bore option expose less employees to hazardous situations.
Schedule	The time span of completing the shaft sinking	First ventilation shaft could be fully sunk within 7 months of commencing the sinking process.	The 3 raise bore option will be completed sooner than the other options.
Production	Dependency on production area	Removal of the broken rock/chips for the raise boring or slipe and line options, there is a risk that these options will have an effect on the shaft production and vice-versa.	Blind sinking is independent of any mine operations and has no dependency on the production.

The following technical risks were identified and assessed:

- Piston effect

If the raise bore, slipe and line option was chosen to construct the shaft, there was a risk associated with the plug of rock produced when the sliping is done in the shaft. When the shaft is sliped, a mass of rock from the blast falls down the raise bore hole and forms a piston down the hole. This may resulted in an air blast at the bottom of shaft and in the shaft up to surface. There also exists a possibility that the plug of rock could get stuck down the hole. This is a huge health and safety risk and will endanger the people working in and around the area. This risk was identified and exclusive to the raise bore, slipe and line execution method.

- Electrical supply

A temporary electrical supply was secured from the local council for 1 100kVA which was sufficient for any of the raise boring options. To drill an 821 meter raise bore hole a HG 330 machine was required, which on full load conditions required 630kVA. For the blind sink or slipe and line options, winders and other major equipment would have been required with at least 3MVA of power. The other available supply was to install the permanent supply from 6^{th} point substation to the site via Paardekraal 2 Shaft, which may have delay the sinking program due to equipment lead times.

- Plant availability

Limited plant was available to sink the 6,9m conventional shaft. The plant required for the smaller 3.8 meter raise bore hole was readily available.

- Previous success

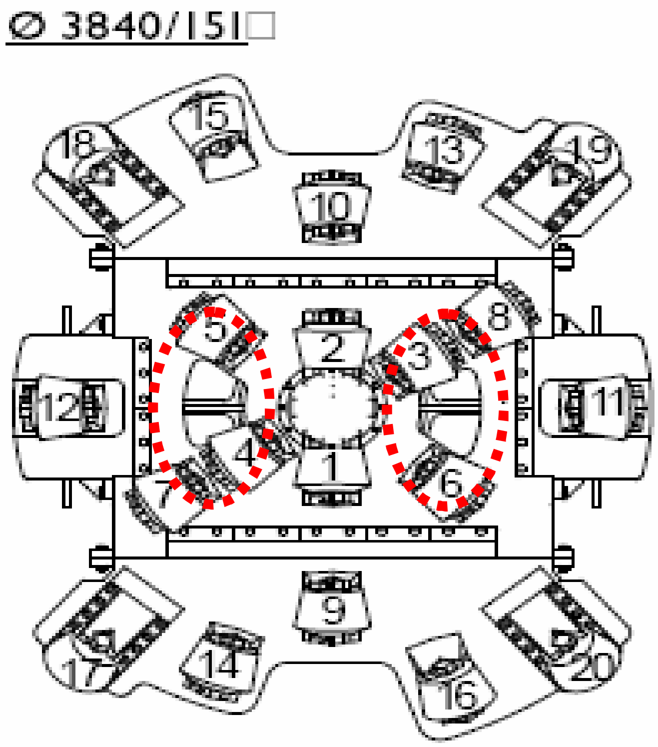
Blind sinking to a depth of 821m is common practice as are small diameter raise bore holes and presented little difficulty. The 6,9m raise bore hole would be the first ever done to a depth of 821m. The raise bore contractors did indicated that it was possible with the equipment available, but that it has not yet been done. Drilling 3 raise bore holes of 3.8 meter diameter at 821 meters respectively was however done.

3. Ground Conditions

A geotechnical risk assessment was completed which recommended that in order to stabilize the larger raise bore hole, support should be installed. The risk with the smaller raise bore holes was less due to the reduced diameter. In order to secure the shaft all options but the three smaller raise bored shafts would have required support. The geotechnical investigations identified poor ground conditions at various areas which would have require support. These ground conditions represented different risks to the different options.
In the blind sink and slipe and line options the risk was deemed to be lower as the shaft could be supported as the shaft progresses and posed little risk to the people and equipment in the shaft when managed.

In the raise boring options the risk of “blocking” the reamer in the poor ground conditions existed, which could cause delays and or damage the reamer. The possibility of key block failure whilst raise boring, posed a risk and was taken in consideration for all the raise bore options. Murray & Roberts Cementation modified the 3, 8 metre diameter reamer whereby the discharged holes on the base of the reamer were opened from 0, 9 square metre to 1, 8 square metre. This however minimized the risk of blocking the discharge holes on the reamer whereupon the cuttings could without restraint have been channeled through the reamer to the bottom of the shaft. These discharge holes were engineered to ensure that the structural strength of the reamer would not be compromised and would be strong enough to endure the thrust forces of the HG 330 raise bore machine. See Picture 1 below.

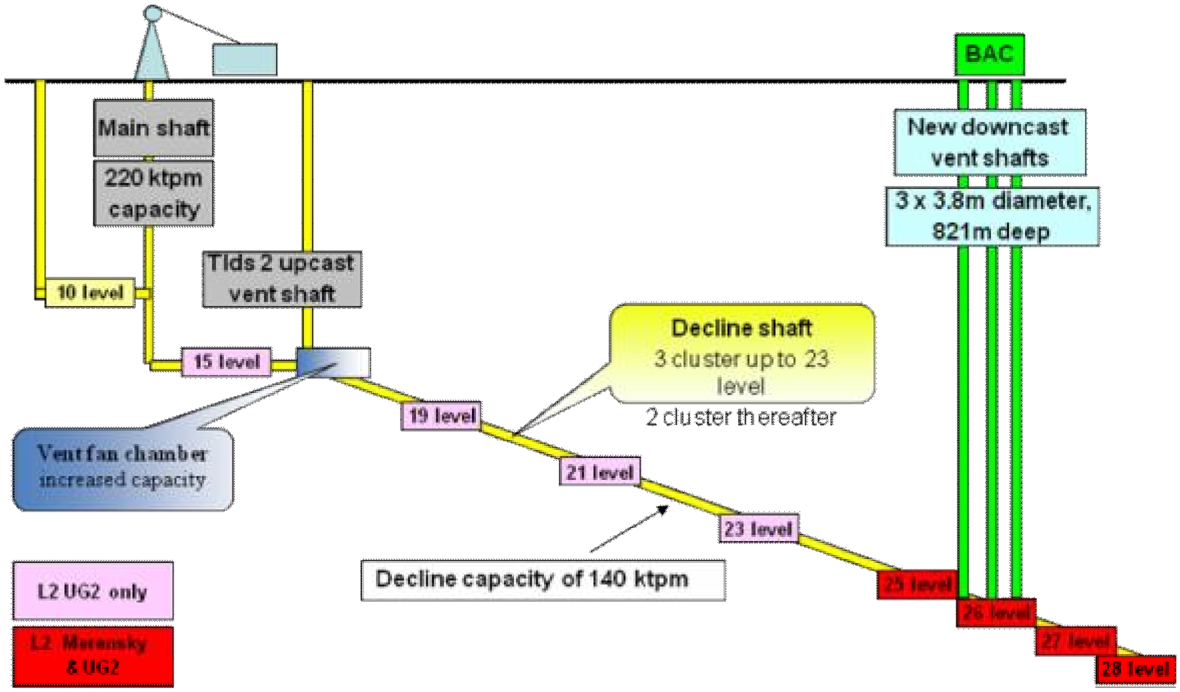
Picture 1 Increased discharge holes on 3, 8 metre reamer base to prevent blocking of reamer. See discharged holes indicated with the red dotted lines.



4. Construction Of Laydown Area.

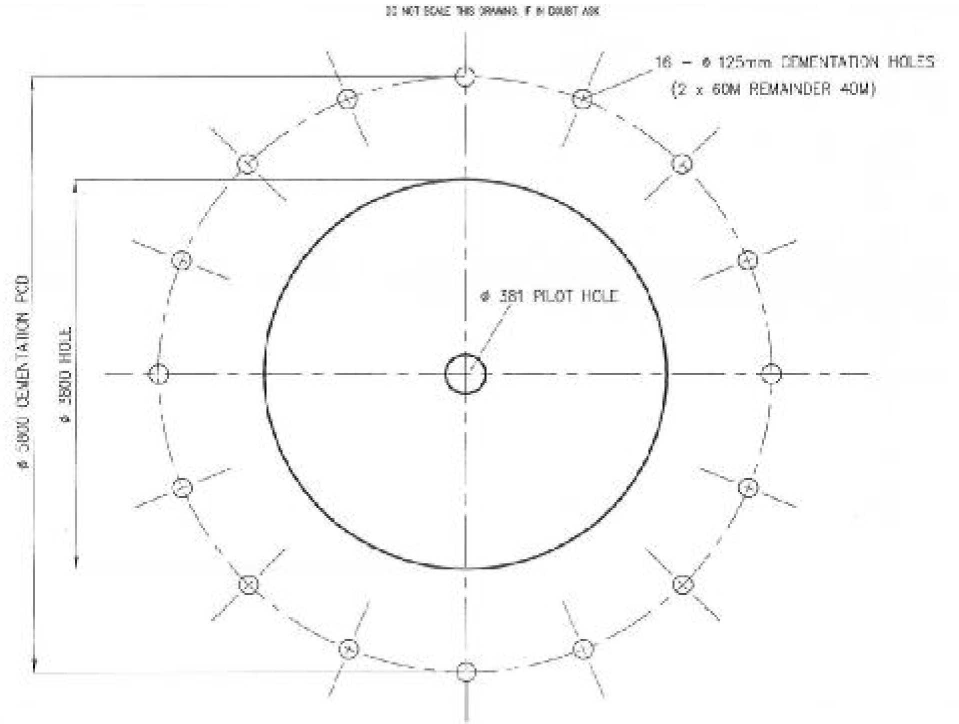
The laydown area was prepared to accommodate the raise bore site and simultaneously have enough room to construct the civil plinths required for the 8MW refrigeration plant on surface. The objective of the project was to increase the overall value to the Townlands Shaft, by supporting the Anglo Platinum Rustenburg Section strategy of 1100 ktpm, whereby the deepening of existing decline to 28 level was required. This project would allow for the mining of the diminishing Merensky reef, and to increase the life of mine of the Townlands Shaft. Through the 3 raisebore holes of 3, 8 metres diameter respectively, with the above mentioned refridgeration plant, an additional air supply of 600 m^3/s will be supplied for the deepened zone, cooling the air down to the calculated 18 degrees Celcius. Picture 2 shows the additional 3 ventilation raisebore holes, allowing the additional air to flow into the deepend zone.

Picture 2 Section view of intergration of the 3 raise bore option into 26 Level.



5. Ground Water Handling

No significant ground water was indicated in the geotechnical exploration hole. However Impala 16 Shaft was sunk in the same general area and a similar distance from known geological structures, and experienced delays in its sinking due to the intersection of an aquifer. The risk of water ingress into the shaft could have been reduced in all options by doing pump pressure tests in the geotechnical hole. Provision could be made to dispose of the water whilst blind sinking, however if water was intersected with a raise borer it would have ran into the mine workings at the bottom of the shaft. The decline area does not have sufficient pumping facilities to handle an influx of water. This meant that a risk of flooding existed for the lower sections of the decline. Proper measures were put into place to address this. All three of the 3, 8 metre diameter shafts were sealed with the curtain grout method. A series of 16 holes were drilled on a 5.8 metre diameter, 1 metre larger on radius than the 3, 8 metre diameter raise bore shaft to a depth of 170 metres respectively. Cement was injected into these holes at a pre-calculated pressure. The head pressure on the cementated holes ensured that the water was pushed away from the raise bore holes and formed a cement curtain on the circumferences of each shaft. On all 3 the raise bore holes a total of 205 tons of cement was pumped. See picture 3 and 4 below.



Picture 3 (above) A plan view of the 16 curtain grout holes on a 5, 8 metre diameter.

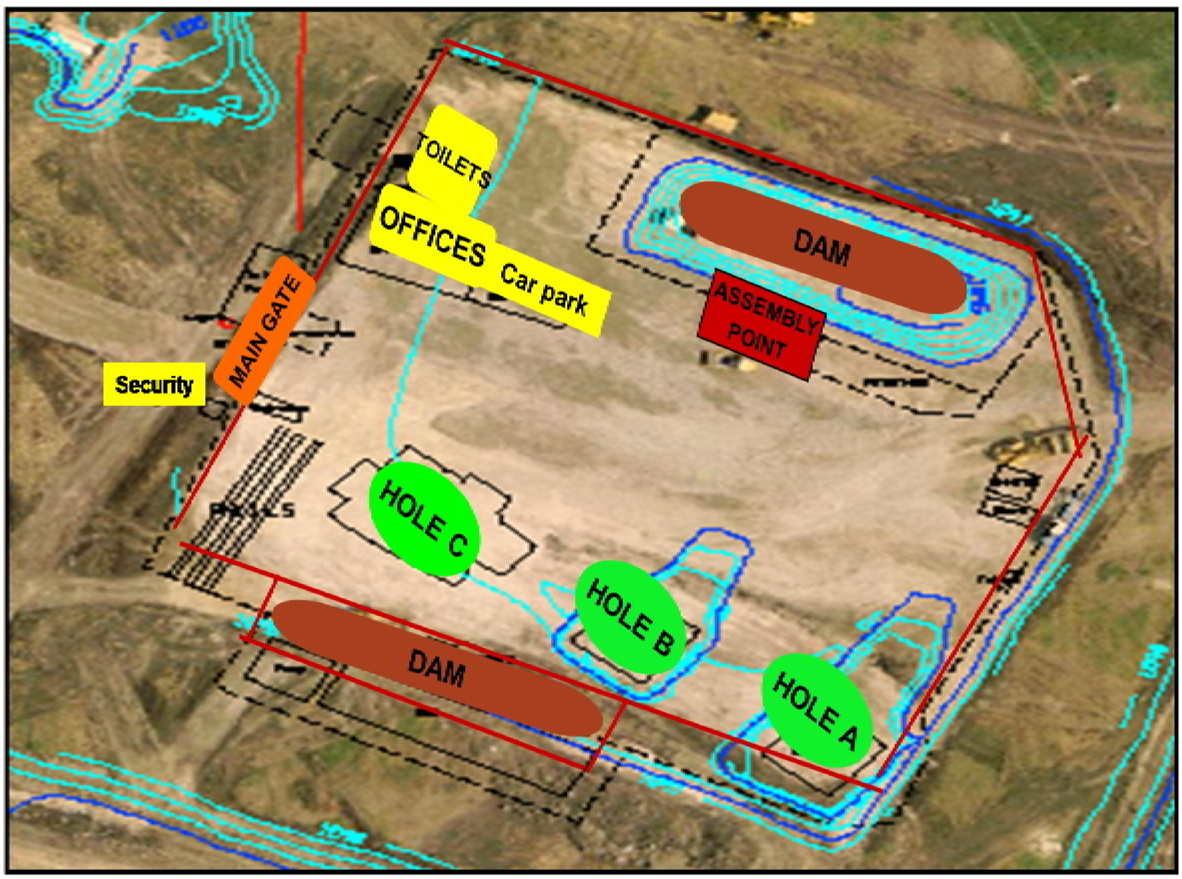
Picture 4 (above) Sub Contractor in progress with the drilling of one 165 mm X 170 metre hole.

RAISEBORING.

6. Methodology

The raise bore HG330 machine was mobilized to site and Murray and Roberts Cementation was responsible for the drilling of the 3 by 381mm pilot holes, the reaming of the 3 by 3, 8 metres diameter shafts and the loading of the reaming cuttings on 26 Level. The terrace construction included the removal of the 3 metre Turf overburden and the thereupon replacement of +/- 23,000 cubic meters of dump rock that was transported from Paardekraal 1 shaft. With the terrace construction and the curtain grouting completed the 3 reinforced raise bore foundations were constructed. See picture 5 below. To accommodate the enormous thrust and torque of the large raise bore machine, a specialized foundation was designed by Murray & Roberts Cementation. The HG 330 machine has a thrust force 9,490 kN and a torque of 540 kNm. The 3 concrete foundations were spaced 28 meters apart measured from centre to centre and consisted of 4 tons of reinforcing and +/- 520 cubic meters of concrete each.

Picture 5 A plan view of the terrace construction indicating the 3 shaft positions.



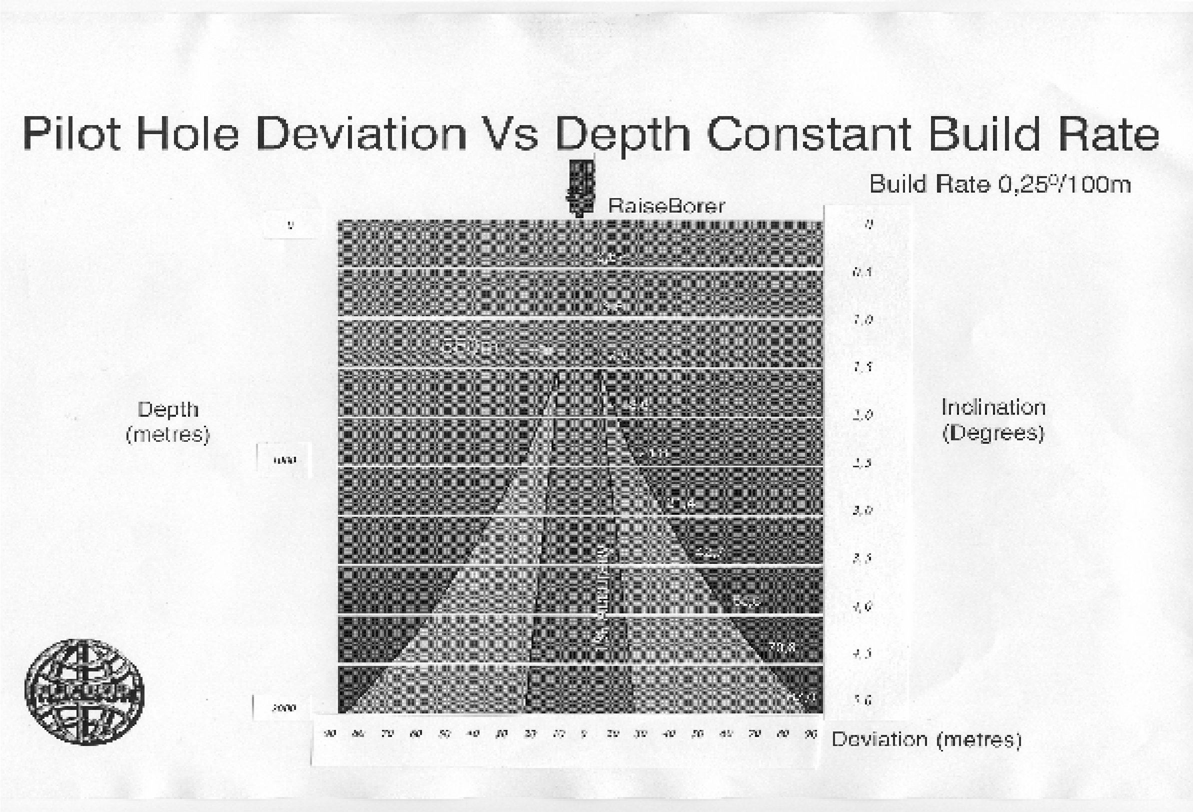
7. Scheduling

A major deciding factor on the four options was the duration of each option. It was determined that the first 2 shafts on the 3 by 3, 8 diameter option would be complete before any of the other options would be finished and would have had a considerable impact on the underground ventilation. See below key milestone dates as was planned with the start of this project.

Key Dates	77 days	02/04/07	05/07/07
Curtain Grouting of 3 x 3.8m Holes	176 days	21/04/07	17/11/07
Drawing and Design Work	16.1 days	23/04/07	16/05/07
Schedule 2: Time Related Items	607.7 days	05/07/07	11/07/09
Civil Works	136 days	06/07/07	11/01/08
Option 3			
Raise Bore 3 x 3.8m Diameter Ventilation Shafts	597.7 days	18/07/07	11/07/09
Site Establishment	19 days	18/07/07	08/08/07
Pilot and Ream 851m x 3.8m Diameter Hole C	194. days	10/08/07	31/03/08
Pilot and Ream 821m x 3.8m Diameter Hole B	189. days	31/03/08	15/11/08
Pilot and Ream 821m x 3.8m Diameter Hole A	190. days	14/11/08	06/07/09
Site Clearance	5 days	06/07/09	11/07/09
Townlands Ventilation Shafts Total Duration	**684.7 days**	**02/04/07**	**11/07/09**

8. Accuracy On The Shafts

The accuracy of the hole was extremely important within the constraints of the underground infrastructure and the fact that the holes are only 28 metres apart. Blind sinking and slipe and line should not have had a high risk of deflection as a result of the execution method The shaft pillar was only to be mined out after the reaming of the shafts has been completed.
Murray & Roberts Cementation indicated that a maximum deflection of 1,2 meter may occur for the smaller raise bore holes if the Rotary Vertical Drilling System was used. Without the use of directional equipment whilst drilling the pilot hole a deflection of +/- 8 meters on the total length of 821 meters was possible, and would have had a significant impact on the project. This detail was based on previous experience with a build rate of 0.25 degrees over every 100 meters advance. See picture 6 below.



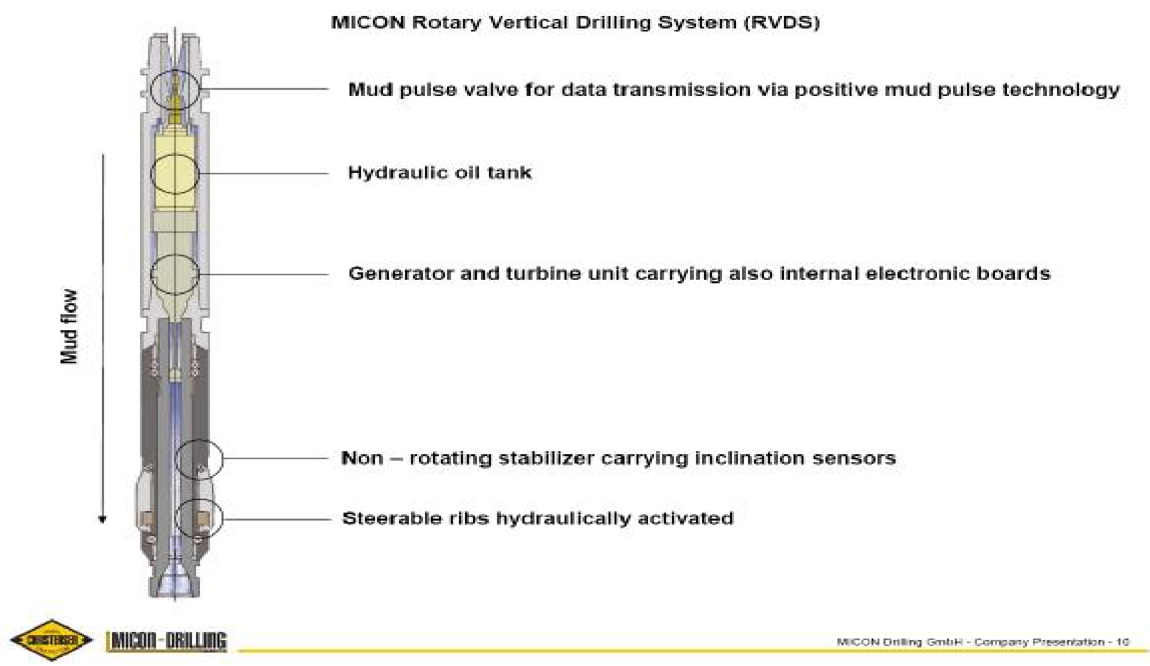
Picture 6 Build Rate at 0.25 degrees over every 100 meters piloted without a directional tool.

9. Rotary Vertical Drilling System (RVDS)

The Rotary Vertical Drilling System is an automatic steering system for drilling vertical holes. The 15" RVDS was developed jointly between Micon (Germany) and Murray & Roberts. Micon's rotary vertical drilling system has been available since the mid 1990's. The system is a closed loop system where two axes are measured continuously with electronic sensors. As soon as a deviation from vertical is detected the four hydraulic cylinders are activated to exert a radial force on the rubbing ribs against the sidewall to correct the deviation. Pressure waves are sent to surface continuously through the flushing water which is converted by a pressure transducer on surface and sent to a computer in the operator's cabin where the condition and steering of the tool is monitored continuously. The first two of the three shafts are complete with an accuracy of 50mm (0,006%) and 10mm (0,001%) deflection over the length of the holes respectively. This equipment is particularly suitable for directional drilling in conjunction with raise boring. This system uses a pair of incline sensors to measure the borehole inclination and transmit the data to an electronics unit. If the pre-programmed directional limits are exceeded, the steering function is initiated by the hydraulic steering system, which extends or retracts the four external, independently operated control ribs.

The extendable stabilizer ribs generate radial forces and work against the angle build-up. The RVDS is supplied to the rig as a complete system consisting of the down hole tool and an independent PC-based surface system. The down hole tool can be divided into two parts, each of approximately 1.5-m length – the Pulser Sub & the Steering Sub. In order to monitor the self-steering drilling process, data signals are transmitted to the surface via positive water pulses and are received decoded and visualised by a surface unit. The upper part of the RVDS, called the Tank-Sub, rotates with the drill string. The outer steerable stabiliser is a part of the lower Steering-Sub. It is non-rotating and running in bearings on the drive shaft. The drive shaft transmits the torque of the drill string to the bit. The non-rotating lower part contains the sensors, the data processing electronics and steering unit. This sub is fitted with radically extendable ribs. The required steering force is generated hydraulically by an oil pump inside the Pulser-Sub and is transmitted to the borehole wall by pistons and steerable ribs. The directional data signals are also transmitted to the mud pulser for further communication to the surface. Both the water pulser for data transmission and alternator for the electrical power supply as well as the pump for hydraulic power supply are housed within the Pulser or Generator Sub. A water turbine drives the alternator and pump. A fully digital electronic unit located in the Steering Sub supplies the two accelerometers with the required voltage. Inclination data is then compared to predetermined data and, if necessary, transformed into steering signals. Subsequently, one or two of the four control valves are being supplied with current. The valves control the cylinder oil pressure, which in turn generates the compensating forces necessary to achieve vertical drilling. The directional data signals are also transformed into a pulse pattern by the digital electronics and they are transmitted to the surface.

The improvements are reflected in the new design (See Picture 7). Various holes have been drilled with better accuracies than 0,15% using the RVDS. On Shaft C 50mm was experienced and on Shaft B only 10mm deflection.



RVDS Operation Parameters

Borehole Diameter: 15"
Tool Type: 12.7/8" (DI 42)

		European	US
Torque:			
	Make up torque Bit - Steerable Stab. Sub:	30 kNm	22 000 ft-lb
	Make up torque Steerable Stab. - Pulser Sub:	120 kNm	88 000 ft-lb
	Make up Torque Pulser Sub - Drillstring:	120 kNm	88 000 ft-lb
Flow Rate:			
	The Gen. voltage must be between 24 Volts and 80 Volts. This Voltage is generated by a mud flow of approximately:		
	Min.:	1000 l/min	265 gal/min
	Max.:	1800 l/min	475 gal/min
Flow / Pressure for RVDS			
	Min. Flow (1000 l/min)	20 bar	290 psi
	Max. Flow (1800 l/min)	30 bar	435 psi
	Recommended Pump (1500 l/min)	30 bar	435 psi
Axial forces:			
	Max. WOB:	25t	55 000 lbs
	Max Pull (if Bit is stuck)	300t	661 000 lbs
	Max. Pull (if Steerable Stabilizer is stuck)	10t	22 000 lbs
Rotation:			
	Operational RPM:	10 - 60 1/min	10 - 60 1/min
	Max: RPM:	70 1/min	70 1/min

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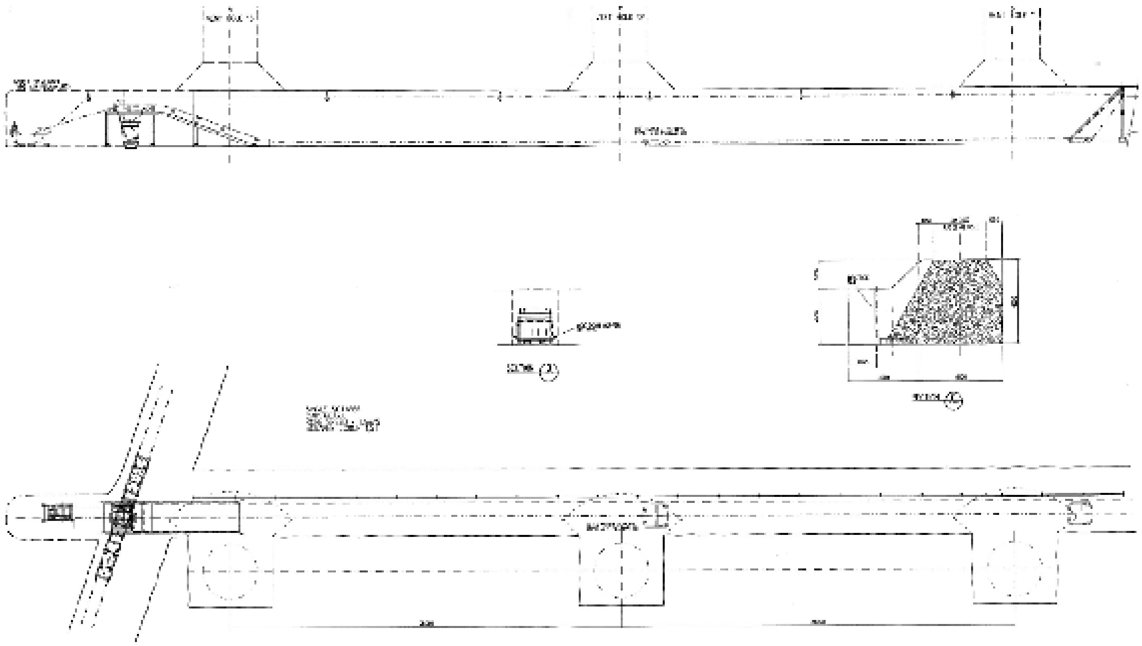
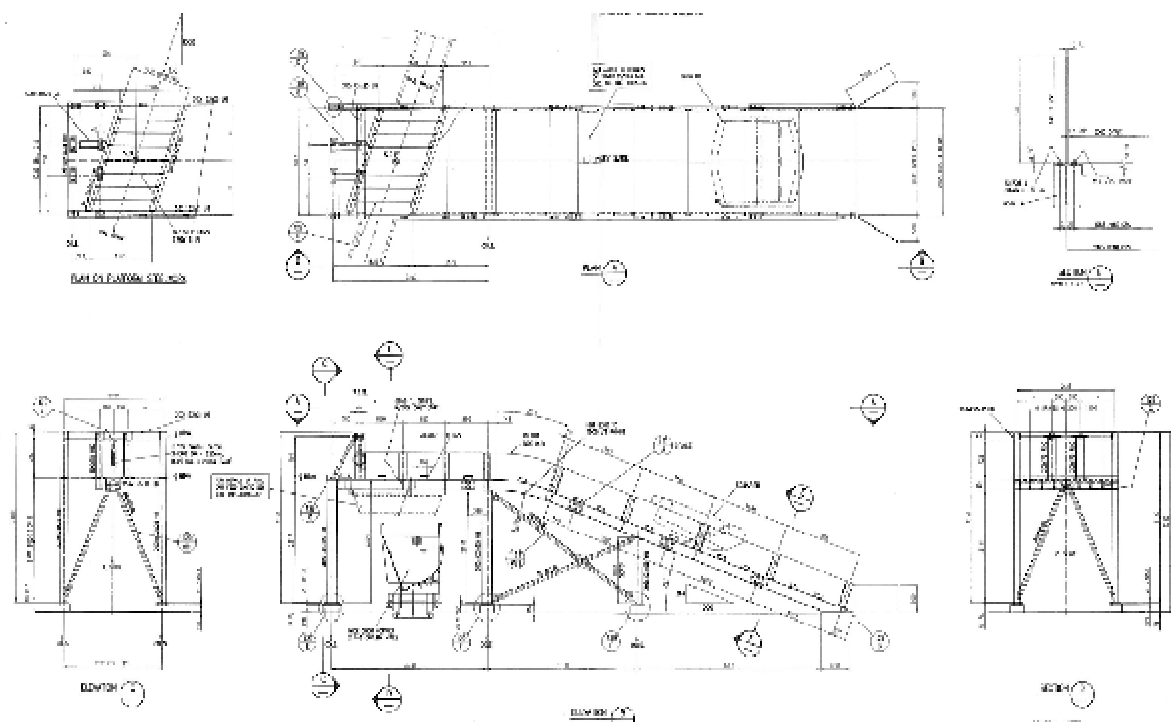
Picture 7 Indicating operational parameters and the Steering and Pulser Subs

10. Chip Handling

The current ore handling system at Townlands Shaft consists of a vertical shaft containing a single rock hoist. The rock hoist is fed from a loading silo of approximately 800 tons capacity. This silo is fed from the mining areas in the vertical shaft as well as from a decline belt system. The vertical shaft produces separate ore streams of Waste and UG2 ore. The decline belt system produces a single feed of conveyor belts in series that require a split in time between Waste, Merensky and in future UG2 ore.
The raise boring of the shaft will result in an additional +/- 400 tons per day of chips per day. A logistics simulation was conducted and indicated that the additional +/- 400 tons can theoretically be removed from 26 Level to the waste dump on surface. For safety reasons it was decided to install a Funkey Slide on 26 Level. This prevented persons from working underneath an open unsupported hole while conducting the loading in the reaming process. The Funkey slide was installed whilst piloting on Shaft C and was suitably positioned to service Shaft C and B reaming cycles. See Picture 8 and Picture 9 below.



Picture 8 Underground loading arrangement with Funkey Slide.



Picture 9 General arrangement of Funkey Slide for underground loading.

11. Conclusion.

With clients being familiar with raise boring for the last 25 years in the mining industries in South Africa, and in the current economical climate the Townlands Ore Replacement Project proved to be the correct choice for vertical excavation. The consistant accuracy successes achieved using the RVDS on Shaft C and B at TORP over 800 metres, indicated that minimal underground development is required as shaft pillars can be developed before the raise bore holes are complete. Reamer chambers can also be developed concurrent with the piloting phase with such high accuracies, and unnecessary delays searching for pilot holes with resultant sliping is minimised. In ground conditions were a wire line geophysical survey indicates that large diameter shafts should be supported then the option of 3 or 2 smaller diameters proved to be a good replacement as completion of the first shaft would provided ventilation that already relieve ventilation restrictions on 30% or 50% completion of the project. The 3 raise bore shafts option furthermore had the lowest comparative risk rating and by carefully considering criteria like, useful life of excavation, plant availability, timing, EMPR amendments approval for blasting on surface, Fall of ground and Fall of men in conventional shaft excavation, raisebore chip handling using the existing shaft infrastructure and water handling underground it is recommended that the option of various smaller raise bore shafts be considered in the planning and concept phase for future projects.

THE WAY FORWARD

12. References

1 Trade off Study Anglo Platinum Rustenburg Section. June 2006
2 Sanire Paper September 2004 Marius Oosthuizen.
3 Micon Drilling GmbH Company Presentation 2008.