Large Diameter Vertical Raise Drilling and Shaft Boring Techniques as an alternative to Conventional Shaft Sinking Techniques

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Raiseboring in South Africa started in 1968 with machines capable of drilling 1,2m diameter raises up to a length of 90m. Today, raiseboring machines are capable of drilling shafts to a diameter of 6,1m to depths in excess of a 1000m. That is an immense improvement from its humble beginnings.

The next step in the evolution of mechanically sinking shafts progressed in 1971 with the use of the first shaftboring machine designed and manufactured in the Federal Republic of Germany, boring a 4,88m diameter, 231m deep shaft.

In the quest for shaft drilling technology it is now possible to sink shafts mechanically up to 8,5m in diameter to 2000m in depth. As less personnel are used the safety risk component is drastically reduced.

The technological improvements in the shaftboring machines (raise boring and V-mole) progressed at an astronomical rate. With the increase in diameter of raisebored holes however, comes greater potential for instability of the sidewall and face of the bored hole.

A systematic flowchart developed by Stacey & McCracken, is discussed to quantify the risks associated with raiseboring and thereby determining the risk attached to any shaft prior to commencement of the excavation so that the reliability of the bored holes can be evaluated.

The capabilities of these machines and associated risks are explained with reference to specific drilling projects.

1. Introduction

Murray & Roberts RUC has been involved in raiseboring contracting since 1978. Murray & Roberts RUC has become the world's largest raiseboring contractor and is considered a leader in the field of large diameter raiseboring. The Company operates a total of 23 raisedrills, which includes 4 Wirth HG330SP type machines, these being some of the largest raisedrills ever manufactured in the world.

Since 1989 RUC has also gained operational experience in shaftboring using the V-mole shaftboring techniques. To date, four major shaft projects have been completed viz.: The Oryx 1B Ventilation Shaft in South Africa, Pasminco's Brokenhill No. 5 Airway in Australia, Anglogold's Western Deep Levels South Mine, sub ventilation shaft and the AlpTransit St Gotthard project in Sedrun, Switzerland. These projects were done in a joint venture with Thyssen Schachtbau GmbH of Germany using a Wirth SBVIII rodless shaftboring machine, better known as a V-mole.

2. Raiseboring

2.1 Modes of Operation

Raiseborers can be used in various modes of operation, the modes most often used are:

- Conventional pilot drilling
- Conventional up reaming of vertical and inclined holes
- Down boring with a pre-drilled pilot hole
- Blind up boring
- Directional pilot and raiseboring used in conjunction with a shaftboring machine (V-mole), for the drilling and supporting of a large diameter shaft.

2.1.1 Conventional Pilot Drilling

A tri-cone pilot bit is normally used varying from 9 inches (229mm) to 15 inches (381mm). The 15 inches (381mm) bit is normally used on long holes with a 12 7/8 inches (327mm) integral drillsteel string with a 10 1/8-inch DI 42 tool joints. During drilling a fluid is pumped through the center of the drillstring to the cutting face, where the rock cuttings are flushed and raised from the bottom of the hole through the annulus around the drillstring to the collar of the hole. The drilling fluid is settled in a closed loop via a series of settling dams so that the drilling water can be re-used.
See figure 1

2.1.2 Conventional Up-reaming of Pilot Holes

On completion of pilot drilling and at such time that the pilot hole breaks through into the lower excavation, a reaming head is fitted to the end of the drillstring. The size of the reaming heads range between 1,2 metres and 6,1 metres in diameter. The head is rotated by the machine and is pulled back against the rock face at the same time. Tungsten Carbide insert cutters are fitted to the head and these cut grooves in the rock in a rotary crushing mode. The 'kerfs' of rock in between the grooves 'spall' out and rock failure occurs in a tensile mode. The rock cuttings fall to the bottom of the hole where it is mucked out by a mechanical loader.

It is a safe, efficient and cost-effective method of making holes through different geological formations with the use of powerful machines, high strength drillstring and reliable heads. The maximum loading capacity of the drillstring limits the diameter as well as the length of the shaft. The loading is dynamic and only approximately calculable because tensile, torsional and bending stresses are overlapping.
See figure 1

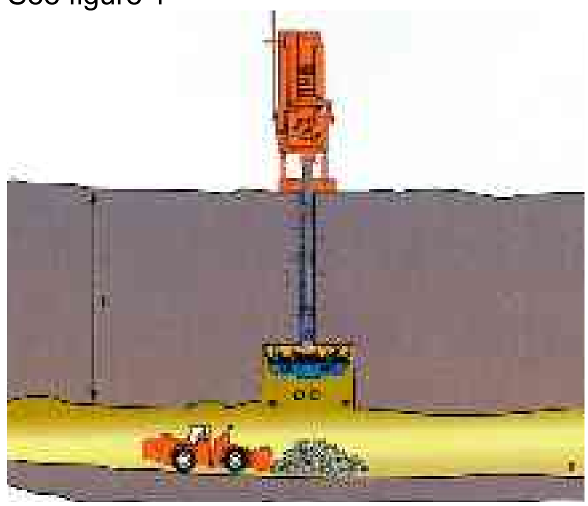


Figure 1

2.1.3 Down Boring with a Pre-drilled pilot hole

In this case an oversize pilot hole is drilled. The cutting head is installed at the top of the pilot hole and drilling takes place in the downward mode. Rock cuttings are flushed down the oversize pilot hole to the bottom of the hole where it is removed. In the case of smaller holes, the machine provides cutter thrust and in the case of large diameter shafts the cutter head is weighted through the addition of steel collars. The down boring method is not used often as the risk of blocking the pilot hole and creating mud rushes at the bottom of the hole is too high.
See figure 2

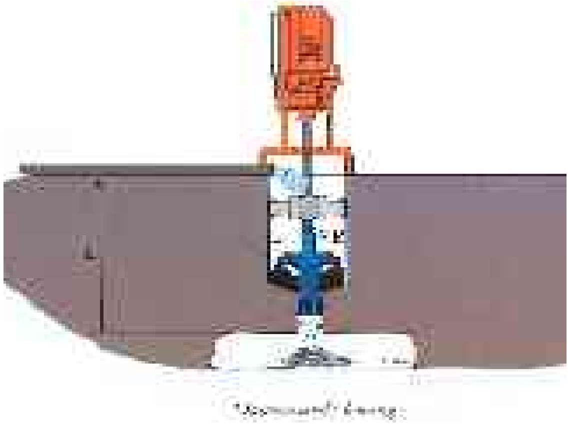


Figure 2

2.1.4 <u>Blind Up Boring</u>

In this case the machine is placed at the bottom elevation and the cutting head drills upwards. Rock cuttings fall to the bottom of the hole where it is deflected into muck cars. This method has limited applications. See figure 3

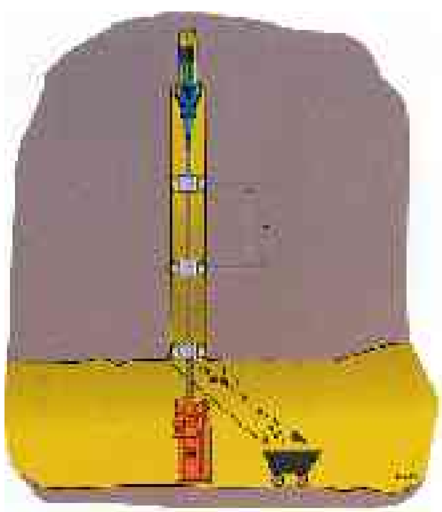


Figure 3

2.1.5 <u>Directional Piloting and Raiseboring</u>

Directional piloting and raiseboring is very costly and is therefore only used in applications where a high degree of accuracy is required. The accuracy of a vertical pilot hole can be guaranteed to depths within the capability of the raisebore machine.

2.2 <u>Breaking New Ground</u>

Murray & Roberts RUC currently holds the following world records:

- Largest diameter shaft raisebored: 7,1m dia, 180m deep at Sasol's Bosjespruit Mine. See figure 4

Figure 4

- Longest hole reamed: 1,83m dia, 1260m deep – HG330 used at the Primsmulde Project, Germany.
  See figure 5

Figure 5

- Hardest rock raisebored: Lava formation with an UCS between 600 and 750MPa – Kloof Gold Mine, South Africa.
  See figure 6

Figure 6

- Longest inclined raisebored hole in the world: 3,5m dia, 755m deep – BCL, Botswana.
  See figure 7

Figure 7

- Deepest shaft V-mole bored: 6,5m dia, 972m deep – Oryx Gold Mine, South Africa
- Largest diameter V-mole shaft bored in hard rock: 7,1m dia, 752m deep – Western Deep Levels Gold Mine, South Africa

2.3 Risks and the control thereof

2.3.1 Deviation of the pilot hole:

Accuracy in pilot holes has been a concern for almost since the invention of mechanized rotary drilling. This problem became much more apparent as operators continued for even longer holes with 1100m not being uncommon anymore.
The deviation of a borehole from its intended path can be attributed to both geological and technical factors, which can be divided into three categories:-

Controllable factors

- Set-up accuracy
- Equipment condition
  - Machine
  - Starter pieces
  - Correct boring tool (bit)
  - Bit sub
  - Stabilizer
- Bit contact pressure (force)
- Rotation speed
- Flushing rate
- Starting procedure

Semi-controllable factors

- Build rate
- Stiffness (design) of the drillstring
- Bit walkrate

Non-controllable factors

- Different rock hardness levels
- Strata dip
- Ground conditions – jointing, fractures, partings, etc.
- Geological features – faults, dykes, bedding planes, etc.

The graph (figure 9) shows a typical deviation with a constant build rate of 0,25 degrees per 100m of drilling. The build rate represents the increase in inclination of the

hole and is measured from the vertical axis. It can be seen that due to the compounding effect the deviation becomes exponential and increases drastically with depth.
In order to minimize deviation any increase in the inclination of the hole should be avoided.
Highly sophisticated survey tools are used to monitor the inclination and direction of the hole. The instruments are capable of detecting movement off the vertical through angles as low as 0,05 degrees in inclination and 0,5 degrees in Azimuth.

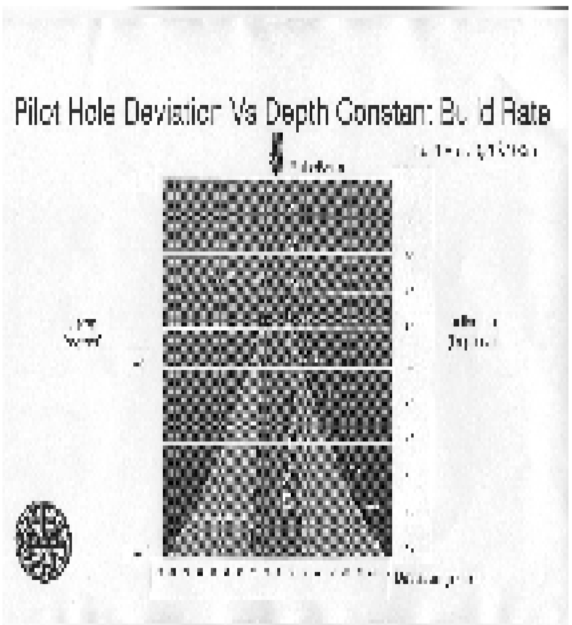


Figure 9

There are two ways in which the direction of the pilot hole can be steered:-

- **Using navigational drilling equipment**

The downhole motor such as the Navi-Drill is used re-actively, i.e. when the hole deviates it is rectified. The Navi-Drill is fitted with an adjustable bent-sub. The motor angle is set to a suitable angle and is lowered down the hole. The motor is then orientated, 180 degrees opposite to the direction of deviation, using the steering tool. The steering tool is fitted with a series of magnetometers and accelerometers that relay information via the wireline conductor to the surface equipment. All data is processed by computer at the collar of the hole and the operator can monitor the motor toolface, as well as the hole direction, on the drillers display unit. A high viscosity mud is then pumped through the drillstring, which causes the mud-motor to rotate at a speed of roughly 120rpm. The drillstring is now moved downward to provide sufficient thrust to the bit, no rotation of the drillstring takes place during the correction-run, rotation is provided through the mud-motor directly to the bit.
On completion of the correction-run the directional drilling gear is removed from the hole and conventional pilot drilling is resumed.
The biggest disadvantage of the Navi-Drill system is that it is used re-actively. To rectify the hole deflection the drillrods must be removed from the hole, the Navi-Drill attached and lowered to the bottom of the hole, which is a very tedious process. The Navi-Drill must be removed when the hole direction has been rectified. To remove the Navi-Drill, the drillrods must be removed. The drillbit must be attached and lowered before piloting can commence. To overcome this problem the self-steering drilling system was developed.
See figure 10

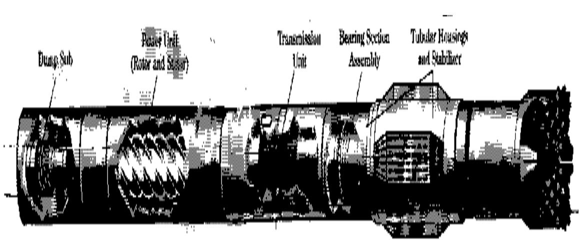


Figure 10

- **Using the Rotary Vertical Drilling System (RVDS)**

The ZBE3000 (DMT GmbH) self-steering directional drilling is in use since the mid 1980's. High maintenance costs and occasional problems necessitated the further development of this type of equipment. New models have been brought out, namely the Well Director, The ZBE4000 and the ZBE5000.

Micon's rotary vertical drilling system has been available since the mid 1990's. This equipment is particularly suitable for directional drilling in conjunction with raiseboring. 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 downhole tool and an independent PC-based surface system. The downhole tool can be divided into two parts, each of approximately 1,5m 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 visualized by a surface unit. See figure 12

The upper part of the RVDS, called the Tank-Sub, rotates with the drillstring. The outer steerable stabilizer 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 drillstring 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/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 tern 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 system for large holes between 15 - 17½'" has been jointly developed by Murray and Roberts RUC and Micon. The improvements are reflected in the new design (See figure 12). Various holes have been drilled with better accuracies than 0,15% using RVDS. Hoisting shafts can now be raisebored by using the Rotary Vertical Drilling System (RVDS).

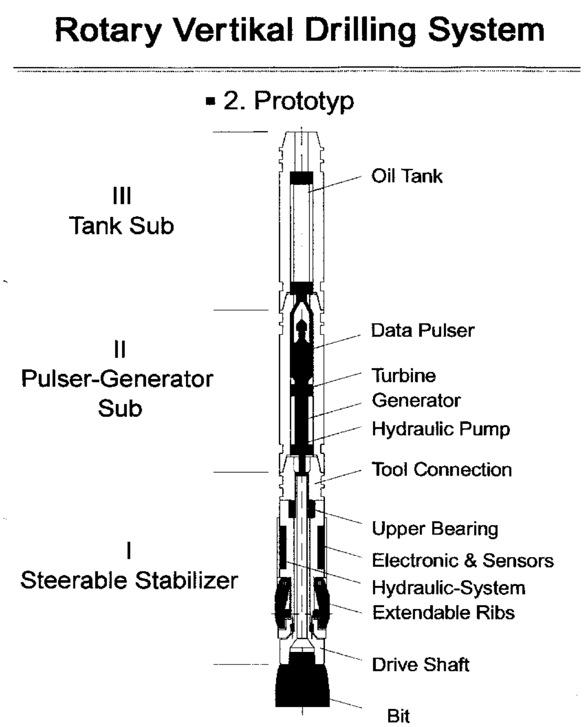


Figure 11

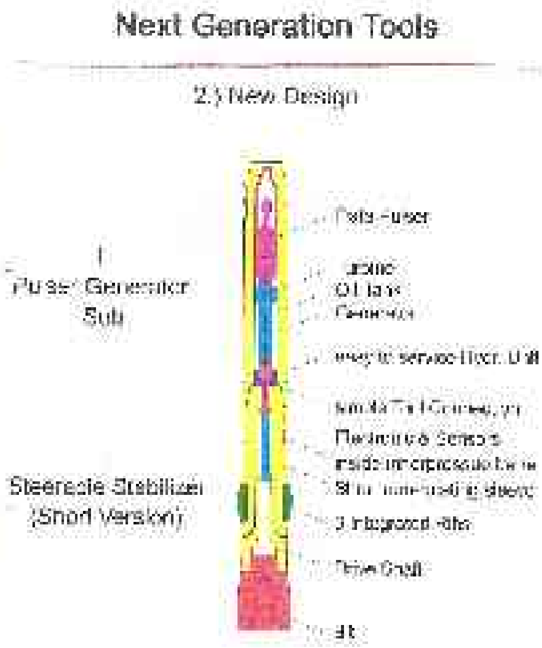


Figure 12

2.3.2 <u>Geotechnical risks for large diameter raisebored shafts:</u>

The two primary geotechnical risks are *boreability* and *stability*. *Boreability* is determined by the hardness and abrasivity of the rock material and by the structure of the rock mass, that is, its jointedness and by machine factors.

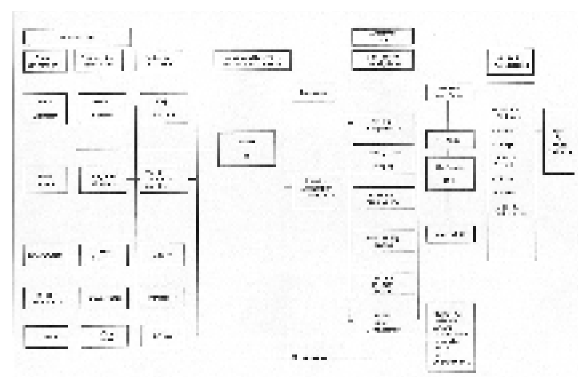
Stability is determined by the rock mass structure, which defines the potential freedom of movement of the rock blocks and by the stresses acting, which provide confinement to the rock mass, but may also be of such a magnitude as to induce failure in the rock material and rock mass.

A detailed geotechnical evaluation or 'raisebore rock quality assessment' based on the Stacey and McCracken method is recommended in the case of deep and/or large diameter shafts, which will be outlined in this paper.

The risk attached to any raisebore project will depend on the confidence with which the rock mass conditions are known. The level of confidence in, or reliability of, information depends on the amount of information that is available, the variation of individual parameters, the impact of this variability on the probable quality and the required minimum rock quality for compatibility with the proposed raise-bored shaft specifications. The important aspect is to assess the rock conditions with respect to the required minimum quality for stability.

A flow chart that sets out the activities to be followed for a systematic assessment of the risk related to the geotechnical aspects of any raise-boring project is presented in Figure 13.

Figure 13



- **<u>Initial risk assessment</u>**

The preliminary geotechnical assessment should be aimed at determining average and lower bound conditions in terms of 'raisability' and stability. The range and distribution of the raise-bore rock quality Q_R and the important parameters RQD/Jn and Jr/Ja must be compared with the required minima for stability at the proposed shaft diameter.

The Q value for the rockmass is obtained from the relation

$$Q = \frac{RQD}{Jn} \times \frac{Jr}{Ja} \times \frac{Jw}{SRF}$$

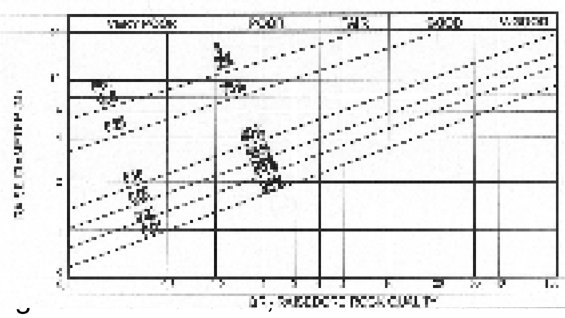
where RQD is rock quality designation
Jn is joint set number
Jr is joint roughness number
Ja is joint alternation number
Jw is joint water reduction factor, and
SRF is stress reduction factor

RQD/Jn gives an estimate of rock block size, Jr/Ja provides an indication of discontinuity shear strength and Jw/SRF

indicates the conditions of active stress surrounding the excavation.
To obtain the raisebore quality index, Q_R from Q, the following adjustment factors, which are cumulative, must be applied.

- Wall adjustment
- Discontinuity orientation adjustment factor
- Weathering adjustment

At the preliminary evaluation stage the risk should only be deemed 'acceptable' if the quality consistently exceeds the required throughout its length. This pre-supposes the availability of sufficient information for this conclusion to be drawn.



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0,05%, i.e. 5%. This is commensurate with an RSR value of 1,3. Given a proposed raise-bore diameter and a rock mass of a certain range of Q_R values, the range of probability of failure can be obtained. If the length of the raise is known, the likely length of raise liable to be affected by failures can be calculated and the volumes of failure determined from stability analyses. A chart showing the probabilities of failure, P(f), or alternatively the reliability, R, of a shaft (where R = 1 – P(f) x 100%), for the range of raise-bore diameters and rock mass qualities is presented as Figure 14.

Figure 14

Suggested levels of reliability, R, and probabilities of failure P(f), that are considered acceptable for the raise-wall stability of different types of excavations are presented in Table 1. These provide guidelines for other raise-bored shafts.

Table 1 : Suggested acceptability of risk for various raise-bored shafts

Excavation	Service Life, (Years)	Reliability R(%)	Probability of Failure P(f)
Unlined hoisting Shaft	>15	99	0,01
Ventilation Shaft	10	95	0,05
Ore Pass	>2	85	0,15
Ore Pass	1	75	0,25

- **Conclusion**

A method of quantifying the geotechnical risk to a raise-bored shaft has been presented above, based on shaft diameter and a raise-bore rock quality index, Q_R.
The approach that has been outlined provide an indication of overall geotechnical feasibility. All excavations must, however, be considered individually and the potential problems should be addressed on merit. The chart presented in Figure 14 does not replace classical analysis as a means of evaluating the incidence and stability of potential failure wedges, but it does allow the probability of failure to be predicted in a simple manner. Comparison of the probability so obtained with the required reliability permits assessment of the overall feasibility and the risk to a proposed raise.
In many cases adverse ground conditions can be treated by cement grouting prior to raiseboring, alternatively advanced planning can be done to carry out support works directly after raiseboring.

3. Shaftboring (V-mole method)

3.1 Background

In the late sixties, following the successful application of tunnel boring machines in gullies and tunnels, thought was given to use this new excavation technique to underground coal mines with a view to fully mechanise tunnel and shaft sinking.
In 1971 the first shaftboring machine was put into service in the coal mines in Germany by a consortium of specialist mining contractors – Deilman-Haniel GmbH (Dortmund) and Thyssen Schachtbau GmbH (Mulheim). The shaftboring machine used was a Wirth GSB-V-450/500 capable

of reaming shafts with a diameter of up to 5m on a pilot hole.
Numerous improvements were made on the machine since 1971, which is reflected in the three machine generations, with the latest model in use being the Wirth SBVII.

3.2 Mode of Operation

The rodless shaftboring machines (V-mole) can be applied to sink deep shafts with a diameter of more than 5m. The requirements for this method are competent rock and a pilot hole between shaft head and shaft bottom of approx. 1,8 to 2,4m diameter with sufficient verticality.
During the boring operation the pilot hole is used to drop the cuttings and is also used for ventilation purposes.
The shaftboring machine, mainly constructed like a tunnelboring machine, widens the pilot hole to the final shaft diameter. Reaming, muck disposal and temporary or final lining of the shaft can be performed continuously and concurrently.
The steering system of the machine guarantees the verticality of the bored shaft with the aid of a laser beam through the centerline of the shaft. The boring diameter can be varied within the range of 5,0 to 8,5m. The depth to be bored is not restricted by the machine parameters. The shaft depth is unlimited as long as a pilot hole is available.

A V-mole shaft construction is carried out in three (3) stages:-

- The raiseboring of the pilot shaft
- The construction of the pre sinked shaft (foreshaft) and the installation of the hoisting facilities
- V-mole boring and the installation of the permanent rock support.

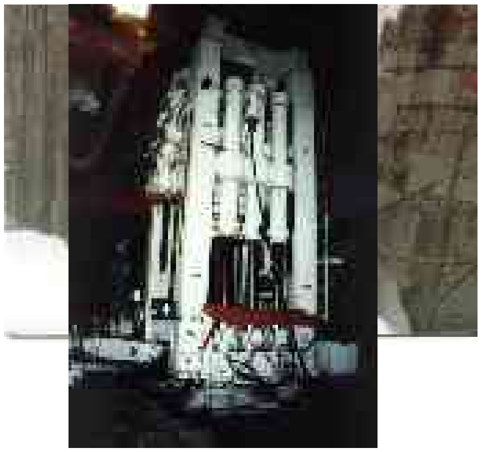
1. The raiseboring of the pilot shaft

The pilot shaft is raisebored using a Wirth HG330 raisedrill. The verticality is ensured by using directional drilling tools, i.e. the Navi-Drill or the RVDS (preferred).
See figure 15

Figure 15

2. Construction of the pre-sinked shaft (foreshaft) and the installation of the hoisting facilities

On completion of the reaming of the center core hole the foreshaft is sliped and lined to a depth of ± 15metres for the assembly of the V-mole. The foreshaft can be sunk before the pilot hole is drilled with the raiseborer. The installation of the hoisting facilities is done concurrently with the pre-sink. The hoisting facilities are required to transport the men and material to the shaft borer (V-mole). See figure 16



3. V-mole boring and the installation of the permanent rock support

The shaft borer (V-mole) then reams the pilot hole to the required size with the rock chips being loaded at the bottom. The shaft can be concrete lined or shotcreted by means of a robotic arm mounted on the stage. The 'drilling' and 'lining' is co-ordinated in an innovative construction unit. The SBVII shaftboring machine is mainly built with a stable frame (outer Kelly), which is hydraulically clamped against the shaft wall by means of twelve gripper pads, arranged symmetrically at two levels of six pads. The rotating inner Kelly includes the main drive shaft, bearings and gears. The upper non-rotating end is square shaped and accommodated in an articulated frame of the outer Kelly. The lower end is carrying the rotating cutterhead, which is powered by six electrical motors of 110kW each.

3.3 Track record

Some fifty-five shafts around the world have been completed successfully with the V-mole. The last four shafts were done by the Joint Venture between Thyssen Schachtbau GmbH and RUC. The Wirth SBVII shaftborer (V-mole) is jointly owned by the two companies.

The joint venture started its first project in 1989 in South Africa. The 972m deep ventilation shaft 1B for the Oryx Gold Mine with a diameter of 6,5m was sunk with the shaftboring machine SB VII. Prior to this operation in South Africa the machine was thoroughly overhauled and prepared for the application in hard rock formations, six electrical motors with 132kW each were installed. The penetration rates achieved at this project were satisfactory. Hard rock formations (e.g. Quartzite) with a compressive strength ranging from 220 to 280MPa were penetrated.

On completion of the Oryx project the joint venture could start a second project namely the ventilation shaft No. 5 in the south field of Pasminco Mining in Broken hill, Australia. During the course of sinking of the 810m deep, 6,5m diameter shaft, the steep formations of amphibolite with a compressive strength of 350MPa and gneiss with approx. 150MPa had to be penetrated. After these two remarkable projects the following conclusions could be made:

- Both shafts could be completed on schedule
- Performances of up to 18m/day (Oryx project) and 12m/day (Pasminco) concrete lined shaft could be achieved, the average performance was 7,6m/day.
- The concurrent operations, drilling and concrete lining, could be conducted undisturbed
- In the course of shaftboring necessary injections could be performed to seal off the fissure waterinflows
- A number of intermediate stations were excavated during the sinking process

V-moling at depth, the ultimate challenge

Anglogold awarded the 752m, 7,1m diameter Sub Vent Shaft construction project to the joint partners Murray & Roberts RUC and Thyssen Schachtbau GmbH. The design brief read as follows:

The new SSV (Sub Shaft Ventilation) is to be sunk from 84 level to 109 level (3312 metres below datum). The SSV shaft must have a 7,0m diameter, (752m deep). The shaft will be used as a return air ventilation shaft and will pass through the mined out reef horizontal between 84 and 109 level.

The exposed sidewall is to be supported by means of 'splitset' anchors, providing the

primary support followed by steel fibre reinforced shotcrete (SFRS) using the shotcrete method in place of the conventional concrete lining. The support of the sidewalls must occur concurrent with the sinking operation of the shaft.
On various levels, throughout the depth of the shaft, return air way (RAW) holings must be provided into the ventilation shaft.
Competitive tenders were submitted for the above consisting of conventional blind sink, slipe and line operations and the V-mole option.
The decision was made in favour of the shaft drilling technique after considering the cost and time advantages of the V-mole method.
The SSV ventilation shaft was the third boreshaft for the joint venture TS & Murray & Roberts RUC, which had to be drilled partly in extremely hard rock formations.
The geological profile shows, that approx. 40% of the formations have a uniaxial compressive strength of more than 300MPa. In the Alberton Lavas the compressive strength was as high as 550MPa. The achieved drilling rates of 0,4m/h are of high importance and very satisfactory.
The experience gained from the two proceedings ‘Oryx’ and ‘Pasminco’ and the knowledge of the geological profile caused the joint venture to design a new cutterhead for the project (Figure 17). This cutterhead has a closed shape in order to achieve a better stabilization and to provide the head with back loaded cutters (Figure 18). The old system with flatly arranged lower part is replaced by a steep new one. All other functions remained unchanged.

Figure 17

Figure 18

The new cutterhead of 7,1m diameter can be equipped with disc-cutters as well as with tungsten carbide cutters.
The shaft sinking activities commenced in May 1995 with the drilling of the pilot hole. This was carried out with Murray & Roberts RUC’s Wirth HG330 raiseborer. The assembly of the shaftboring machine took approximately 6 weeks. The 752m deep ventilation shaft was completed under extremely difficult geological conditions. The highest performance attained under these conditions was a monthly advance rate of 137m in the Alberton Lava formation. After drilling through the lava formations scaling occurred in the quartzite formations at 104 level, which necessitated increased temporary support.
The pilot hole ‘dog-eared’ and had to be filled (see Figure 19). A platform was erected underneath the head. A unique site specific design shutter was installed

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Figure 19

Figure 20

New technologies were introduced for the shaft lining. The splitset pattern bolting, (SS39) combined with steel fibre shotcrete was applied as the final lining with a fully mechanized system:

The bolting with a rock bolt density of 1 bolt per m^2 respectively was done fully automatically and concurrently with drilling using two Atlas Copco drill rigs mounted on the rotating and telescoping topdeck of the shaftboring machine (See figure 21).

Figure 21

The application of the steelfibre-microsilica-wetshotcrete with 50MPa strength was also fully automatic by means of a robotic nozzle, which was situated on an independent operating sinking stage with three decks above the shaftboring machine. (See figure 22)

Figure 22

The SSV-Ventilation shaft of the Western Deep Levels Mine is the world's biggest, largest and deepest bored shaft.
It is remarkable for its successful penetration of one of the hardest rock

formations with compressive strengths of up to 550MPa.

The St Gotthard Base Tunnel – Sedrun Vent Shaft

The latest venture between the joint venture partners Murray & Roberts RUC and Thyssen Schachtbau is a 785m, 7,1m diameter vent shaft in Sedrun, Switzerland. The Sedrun vent shaft is part of the AlpTransit Gotthard project, which could well be the construction project of the new century. The 57km long base tunnel under the St Gotthard massif is the core project of a new railway link through the Alps, with future passenger trains traveling at speeds of up to 250km/h through the longest railway tunnel in the world.

The 57km tunnel stretches from Erstfeld in the north to Bodio in the south.

See figure 23 & 24

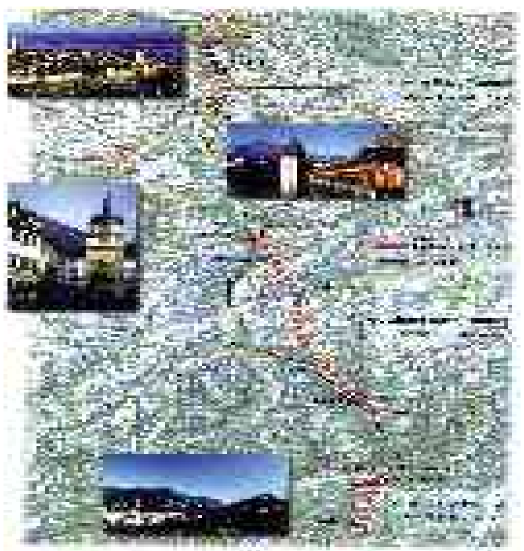

Figure 23

Figure 24

At 1,340m above sea-level a horizontal tunnel of 1km reaches the top of the first 785m deep subshaft, which was sunk conventionally and equipped with a high performance hoisting system. Thirty metres alongside Shaft I is the locality of Shaft II, which is designed for ventilation purposes. The shaft was originally planned as a raisebore shaft of 4,5m diameter. A proposal by the JV Thyssen-RUC-Oestu, which envisaged to sink the shaft using the rodless-shaft-boring method with 7,1m diameter was preferred by the client, JV Transco. The most important advantage for the client is that it provides another major access to the tunnel construction site with four headings and a second hoisting facility for the big assembly parts of the large tunnel construction machines. The proposal of the shaft boring JV also includes the installation of a heavy duty hoisting system in the shaft, which during the shaft sinking period serves as a kibble winder.

The shaft construction works commenced mid May 2002. The raisebore machine (Wirth HG330SP) was installed at the shaft collar for both directional pilot drilling at 381mm diameter and the subsequent reaming of the hole to 1,83m diameter. The vertical drilling system RVDS of Micon was applied for the directional drilling. Despite the unfavorable geology, with numerous vertical joints, the deviation from vertical was only 28cm(0,036% accuracy). The reaming of the pilot hole from 381mm to 1,83m diameter was conducted without problems and completed by mid November 2002.

After the completion of the pilot shaft the installation of the shaft sinking equipment and the shaftboring machine commenced. The V-mole, type Wirth BSV VI with a 7m borehead, dressed with a combination of disc and tungsten carbide cutters were utilized. The drilling operation started in February 2003 and was completed end June 2003 with an average drilling performance of approximately 7m/day. The continuous drilling and shotcrete lining system which was perfected at Western Deep Levels Gold Mine was used.

See figure 25

Figure 25

3.4 <u>Risks and the control thereof</u>

The biggest risk in using the V-mole method is the scaling 'dog earning' of the pilot hole.

As ground stresses are increasing with depth it was experienced that at deep levels spalling occurs in any kind of vertical opening, e.g. boreholes or shafts. The so called 'dog-earing' starts as soon as the shaft wall is exposed and it becomes visible at the shaft wall as spalling and rock bursting. (See figure 19)

Depending on the stress intensity and excavation diameter the depth of the disintegration of rock can vary and may be very different.

For future applications of shaftboring machines the following conclusions and recommendations are deprived from experiences made in the past in relation with the abovementioned occurrences:

- Determination of the individual pilot hole diameter by assessing the obtainable geological-geotechnical date of the rock formation to be drilled through
- There is a correlation between the hole diameter and the scaling 'dog-earing'
- The pilot hole can be reduced to 1,83m (optional) by using the RVDS. The pilot hole can be drilled accurately therefore no blasting is required of the pilot hole whilst V-moling

4. Conclusion

The mining industry's requirement for safe, rapid and economical mine development is met by the mechanical shaftboring methods described. The technique has provided an economically sound solution for a large variety of different requirements, especially in those projects executed in recent years involving deep, large diameter holes. Raiseboring to a depth exceeding 1,000m and at diameters of up to 6m is no longer uncommon. The method continues to be developed to cover an increasingly wide range of circumstances. The improvements made in directional drilling now enables hoisting shafts to be raise bored, either in one pass or in combination with the V-mole.

By using the systematic risk assessment developed by A McCraken and TR Stacey, a quantitative assessment of the risk attached to any shaft prior to commencement can be done.

The capabilities and effectiveness of the raiseboring and V-mole techniques have been proven in the execution of more than 50 projects throughout the world, with an accumulated depth of 21,000m and in a wide variety of rock types.

'Using alternative scenarios, the future literally becomes a matter of choice, not change'. (Wolfgang Grukke)

5. References

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