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

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SYNOPSIS

Raise drilling in South Africa started in 1968 with machines capable of drilling 1.2 meter diameter raises up to a length of 90 meters. Today’s raise drilling machines are capable of drilling vertical shafts to a diameter of 6.1 meters to depths in excess of a 1 000 meters and 7.1 meters to 200 meters in depth. That is an immense improvement from its humble beginnings.

In 1971 the first shaft boring machine was designed and manufactured in the Federal Republic of Germany and bored a 4.88 meter diameter, 231 meter deep shaft.

In the quest for mechanical shaft sinking technology it is now possible to sink vertical shafts mechanically up to 8.5 meter in diameter to 2 000 meters in depth. Fewer personnel are required with mechanisation, and due to the methodology used, safety aspects are improved with overall risk drastically reduced.

Conventional shaft sinking is briefly discussed and compared to large diameter raise drilling and shaft boring.

The technological improvements in shaft boring machines (raise drilling and V-mole) have progressed at an accelerated rate. Under certain geological conditions, with the increase in diameter of raise drilled holes, however, comes greater potential for instability of the exposed sidewalls of the drilled hole.

A systematic flowchart developed by Stacey & McCracken, is discussed to quantify the risks associated with raise drilling and shaft boring and thereby quantifying the risk attached to drilling a relatively large shaft prior to commencement of the excavation in order to assess the stability of the bored hole. Managing this risk now becomes the engineer’s challenge.

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

INTRODUCTION

Murray & Roberts RUC has been involved in raise drilling contracting since 1978. Murray & Roberts RUC has become the world’s largest raise drilling contractor and is considered a leader in the field of large diameter raise drilling. The Company operates a total of 23 raise drills, which includes four Wirth HG 330 SP and one Robbins 123R machines, these being some of the largest raise drills ever manufactured in the world.
Since 1989 RUC has also gained operational experience in shaft boring using the V-mole shaft boring technique. To date, four major shaft projects have been completed utilizing the V-mole technique, these being:

- Oryx No 1B Ventilation Shaft in South Africa
- Pasminco’s Broken Hill No. 5 Airway in Australia
- AngloGold’s Western Deep Levels South Mine sub vertical ventilation shaft in South Africa and
- AlpTransit St Gotthard project in Sedrun in Switzerland.

These projects were undertaken in joint venture with Thyssen Schachtbau GmbH of Germany using a Wirth SBVII rodless shaft boring machine, better known as a V-mole.

### RAISE DRILLING TECHNIQUES AND HISTORY

#### Modes of Operation

Raise borers can be used in various modes of operation and 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 piloting and raise drilling used in conjunction with a shaft boring machine (V-mole), for the boring of a large diameter shaft.

#### Conventional Pilot Drilling

A tri-cone pilot bit is normally used varying from 9 inches (229mm) to 15 inches (381mm). The 15 inch (381mm) bit is normally used on long holes with a 12 7/8 inches (327mm) integral drillsteel string with 10 1/8-inch DI 42 tool joints.

#### 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 attached to the end of the drillstring. The size of the reaming heads range between 1.2 meters and 7.1 meters in diameter.

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 reamer 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 calculateable as tensile, torsional and bending stresses are overlapping. (See Figure 1)
**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. 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 high. (See Figure 2)
**Blind Up Boring**

In this case the machine is placed at the bottom of the planned hole position and the cutting head drills upwards. Rock cuttings fall to the bottom of the hole where they are deflected into muck cars or an alternative mucking arrangement. This application is widely practiced in South African deep tabular orebody mines with hole lengths ranging from 30 to 90 meters under normal circumstances and up to 190 meters in special applications. (See Figure 3)

![Figure 3 Blind Boring](image)

**Directional Pilot Drilling**

Directional pilot drilling is 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 raise drill machine and accuracies of 0.036% have recently regularly been achieved. Refer to paragraph 4.1.

**Recent Achievements (Breaking New Ground)**

Murray & Roberts RUC currently holds world records and has had the following achievements:

- Largest diameter shaft raise drilled to 7.1 meters in diameter and 178 meters of vertical depth at Sasol Coal’s Secunda Collieries’ Bosjespruit Mine. (See Figure 4)
• Longest vertical hole reamed to 1.83 meters in diameter and 1260 meters deep at the Prismulde Project, Germany.

• At Kloof Gold Mine South Africa a 1 100 meter deep 4.1 meter diameter hole was drilled through the hardest rock formation being Lava with an UCS between 600 and 750 Mpa.

• Longest inclined raise drilled hole to 3.5 meters in diameter and 755 meters deep at BCL in Botswana (See Figure 5)

• Deepest shaft V-mole bored in South Africa to 6.5 meters in diameter and 972 meters deep at Oryx Gold Mine

• Deepest shaft V-mole bored at Prismulde Germany to 7.8 meters in diameter and 1260 meters deep by Thyssen Schachtbau of Germany

• Largest diameter V-mole shaft bored in hard rock to 7.1 meters in diameter and 785 meters deep at Alp Transit, St. Gotthard, Sedrun, Switzerland.

• At Impala Platinum Mine South Africa drilled a 1 050 meter long 5.1 meter diameter raise drill hole through norites with RVDS with 0.05 % accuracy

• At Sedrun in Switzerland drilled a 785 meter long 1.83 meter diameter hole with RVDS with 0.035 % accuracy i.e. 280 mm deviation

• At Moab Khotsong in South Africa drilled a 360 meter long 3.8 meter diameter hole with RVDS with 0.063 % accuracy i.e. 223 mm deviation

• At Prismulde in Germany drilled the 1 260 meter long 1.83 meter diameter hole with down-the-hole motor with 0.04 % accuracy i.e. 450 mm deviation

• At Impala Platinum Mine South Africa drilled a 1 090 meter long 5.1 meter diameter hole through norites
SHAFT BORING (V-MOLE METHOD)

Background

In the late sixties, following the successful application of tunnel boring machines in tunnels, thought was given to use this new excavation technique to underground coal mines with a view to fully mechanise tunneling and shaft sinking.

In 1971 the first shaft boring machine was put into service in the coal mines in Germany by a consortium of specialist mining contractors namely Deilmann-Haniel GmbH (Dortmund) and Thyssen Schachtbau GmbH (Mulheim). The shaft boring machine used was a Wirth GSB-V-450/500 capable of reaming shafts with a diameter of up to 5m from a center core pilot hole.

Mode of Operation

The rodless shaft boring machines (V-mole) can be applied to sink deep vertical shafts with a diameter of up to 8.5m. The requirements for this method are:

- Relatively competent rock as determined through the study techniques mentioned above (unsupported center core to stand up)
- And a reamed pilot hole between shaft head and shaft bottom of approximately 1.83 to 2.4 meters in diameter with sufficient verticality to serve as a center core. During the boring operation this center core pilot hole is used to drop the reamed cuttings to the bottom of the new shaft and is also used for ventilation purposes.
The shaft boring machine constructed similarly to a tunnel boring machine, (TBM), widens the center core pilot hole to the final shaft diameter by reaming downwards. Reaming, muck disposal, shaft support and permanent shaft equipping are 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 a range of 5.0 to 8.5m. The depth to be bored is not restricted by the shaft boring machine parameters, but becomes a factor of the ability to drill and ream a pilot hole to 1.83 meter in diameter. We know that the drilling of holes of 1 300 meters in length is possible and has been done before. The next challenge will be to drill a 1.83 meter diameter hole over a continuous length of more than 1 300 meters. The shaft depth is therefore unlimited as long as a center core pilot hole is available.

A V-mole shaft construction is carried out in various stages:

- The raise drilling of the pilot hole and center core to serve as a rock pass
- The construction of a pre-sunk foreshaft to facilitate the installation of the v-mole machine
- The installation of the necessary and required hoisting facilities
- V-mole boring, shaft support and equipping
- The final removal of the v-mole at shaft bottom
- And commissioning of the permanent shaft system

The raise boring of the pilot shaft:

The pilot shaft is raise bored using a Wirth HG330 raise drill (See Figure 6). Using directional drilling tools, i.e. the Navi-Drill or the preferred RVDS, ensures the verticality.

![Figure 6](image)

(HG 330 Machine) (Hooking a Reamer)

Construction of the pre-sunk shaft (foreshaft) and the installation of the hoisting facilities

On completion of the reaming of the center core pilot hole, the foreshaft is slipped and lined to a depth of ± 11 meters for the assembly of the V-mole. The foreshaft can be sunk before the pilot hole is drilled with the raise borer. 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).
**V-mole boring and the installation of the permanent rock support**

The shaft borers then ream the center core pilot holes 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 coordinated in an innovative construction unit. The shaft boring machine SB VII is mainly built with a stable frame – outer kelly – which is hydraulically clamped against the shaft wall by means of 12 gripper pads, arranged symmetrically in 2 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 132kW each.

**Track Record**

Some fifty-five vertical shafts around the world have been successfully bored with V-mole machines. Four shafts were constructed by the Joint Venture between Thyssen Schachtbau GmbH and Murray & Roberts RUC. These two companies jointly own the Wirth SB VII shaft borer in South Africa.

**Joint Venture first**

The joint venture started its first project in 1989 in South Africa, constructing the 972 meters deep, No 1 B ventilation shaft at Oryx Gold Mine, to a diameter of 6.5 meters, with the shaft boring machine SB VII.

The penetration rates achieved on this project were satisfactory, considering hard quartzite rock formations with compressive strengths ranging from 220 to 280 Mpa were penetrated.

**Joint Venture second**

Upon 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. In the course of the sinking of the 810 meter deep shaft with a diameter of 6.5 meters, steep rock formations of amphibolites with a compressive strength of 350Mpa and gneiss with approximately 150 Mpa were penetrated. After these two remarkable projects the following conclusions could be made:

- Both shafts were be completed on schedule;
- Performances of up to 18 m/day (Oryx project) and 12 m/day (Pasminco) concrete lined shaft could be achieved with an average performance of 7.6 m/day;
- The concurrent support drilling and installation as well as concrete lining, could be done undisturbed;
- During the course of shaft boring, the necessary injections could be performed to seal off the fissure water inflows;
- A number of intermediate stations were excavated during the sinking process.

**Joint Venture third, V- mole at depth, the ultimate challenge**

AngloGold South Africa awarded the 752 meter, 7.1 meter diameter Sub Ventilation Shaft construction project at the then Western Deep levels South Mine to the joint partners Murray & Roberts RUC and Thyssen Schachtbau GmbH.

The geological profile showed that approximately 40% of the formations had a uni-axial compressive strength of more than 300Mpa. In the Alberton Lavas the compressive strength was as high as 550Mpa. The achieved drilling rates of 0.4 m/hour were very satisfactory.
The experience gained from the two preceding projects “Oryx” and “Pasminco” and the knowledge of the geological profile caused the joint venture to design a new cutter head for the project (See Figure 7). This cutter head has a closed design in order to achieve better stabilization and to provide the head with back loaded cutters (See Figure 8).

Figure 7
V-Mole Head

Figure 8
Cutter
The shaft sinking activities commenced in May 1995 with the drilling of the pilot hole and center core to a diameter of 3.5 meters. This was carried out with Murray & Roberts RUC’s Wirth HG 330 raise borer. The assembly of the shaft boring machine took approximately 6 weeks. The 752 meter deep ventilation shaft was completed under extremely difficult geological conditions. The highest performance attained under these conditions was a monthly advance rate of 137 meters in the Alberton Lava formation. After drilling through the lava formations, scaling occurred in the quartzite formations at 104 level (+-3 200 meters below surface), which made increased temporary support density necessary.

The center core pilot hole “dog-eared” excessively from the original 3.5m diameter size due to stresses at this great depth underground.

The shaft sidewall bolting with a rock bolt density of one bolt per m² was done fully automatically and concurrently with boring by using two Atlas Copco drill rigs mounted on the rotating and telescoping top deck of the shaft boring machine. (See Figure 9).

![Figure 9: Support Deck](support_deck.jpg)

The application of the steel fibre micro silica wet shotcrete with 50Mpa strength was also fully automated by means of a robotic nozzle, which was situated on an independent operating sinking stage with three decks above the shaft boring machine. (See Figure 10).

The project construction was remarkable for its successful penetration of one of the hardest rock formations with compressive strengths of up to 550Mpa.
Joint Venture fourth, the St Gotthard Base Tunnel - Sedrun Ventilation Shaft

The latest venture between the joint venture partners Murray & Roberts RUC and Thyssen Schachtbau is a 785 meter deep 7.1 meter diameter ventilation shaft in Sedrun, Switzerland. The Sedrun 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 shaft construction works commenced mid May 2002. The raise bore machine Wirth HG 330 SP was installed at the shaft collar for both directional pilot drilling to 381mm diameter and the subsequent reaming of the center core pilot hole to 1.83 meter in diameter. The vertical drilling system, RVDS, of Micon was applied for the directional drilling. Despite the unfavourable geology with numerous vertical joints, the deviation from the vertical was only 280mm (0.036% accuracy). The reaming of the pilot hole from 381mm to 1.83 meter 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 shaft boring machine commenced. The V-mole, type Wirth VSB VI with a 7.1m borehead was dressed with a combination of disc and tungsten carbide cutters and a total installed power of 520kW. The shaft boring operation started in February 2003 and was completed by the end of June 2003 with an average boring performance of approximately 7m/day.
RAISE DRILLING RISKS AND RISK MANAGEMENT

Deviation of the Pilot Hole

Accuracy of pilot drilled holes has been a concern almost since the invention of mechanized rotary drilling. This problem became much more apparent as operators required the drilling of longer holes with lengths of 1 100 meters, this not being uncommon anymore and competing with blind sunk vertical shafts.

The deviation of a borehole from its intended path can be attributed to both geological and technical factors, which can be divided into two main categories:

Controllable factors

- Set-up accuracy of a machine
- Equipment condition
- Bit contact pressure (force)
- Rotation speed
- Flushing rate
- Starting procedure

Non-controllable factors

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

Highly sophisticated survey tools are used to monitor the inclination and direction of a 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.

There are two ways in which the direction of the pilot hole can be steered and these being:

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 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 being 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 again. The drill bit must again be attached and lowered before piloting can commence. To overcome this problem the self-steering drilling system was developed. (See Figure 11)
Micon developed a rotary vertical drilling system, (RVDS), and this has been available since the mid 1990’s. This equipment is particularly suitable for directional drilling in conjunction with raise drilling. This system uses a pair of incline sensors to measure the borehole inclination and transmit the data to an electronic 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.

Murray & Roberts RUC and Micon have jointly developed the system for large pilot holes, between 15 – 17½”. The improvements are reflected in the new design (See Figure 13). Various holes have been drilled with accuracies of 0.04% using the RVDS. Hoisting shafts can now be raise drilled by using the Rotary Vertical Drilling System (RVDS) to drill the pilot from there the final hole.
Geotechnical risks associated with large diameter raise drill shafts

The two biggest geotechnical risks are boreability and stability.

Prof. T R Stacey and A McCracken have written numerous papers on risk analysis and some aspects are briefly discussed in this section.

Boreability is determined by the hardness and abrasiveness of the rock material and the structure of the rock mass, that is, it’s jointing and then also by the raise drilling 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 ‘raise bore rock quality assessment’ based on the Stacey and McCracken method is recommended in the case of deep and/or large diameter shafts and is briefly discussed.

The risk attached to any raise bore project is dependant 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 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 drilled shaft specifications. The important aspect is to assess the rock conditions with respect to the required minimum quality for stability.

A flow chart, developed by Prof. Dick Stacey, that sets out the activities to be followed for a systematic assessment of the risk related to the geotechnical aspects of any raise drill project is presented in Figure 14.
**Initial risk assessment**

The preliminary geotechnical assessment should be aimed at determining average and lower bound conditions in terms of “raise ability” and “stability”. The range and distribution of the rock quality, QR 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 alteration 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 raise drilled hole quality index, QR from Q, the following adjustment factors, which are cumulative, must be applied.

- Wall adjustment
- Discontinuity orientation adjustment factor
- Weathering adjustment

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**Figure 14**

Systematic Risk Assessment Chart
At the preliminary evaluation stage the risk should only be deemed “acceptable” if the quality consistently exceeds the requirement throughout its entire length. This presupposes the availability of sufficient information for this conclusion to be drawn.

**Final risk assessment**

The assessment of risk will depend ultimately on the acceptability of failures within the raise drilled shaft and on the incidence and volume of failures that can be tolerated. In general, an acceptable probability of failure of a raise drilled shaft, given its function, is considered to be 0.05 i.e. 5%. This is commensurate with an RSR value of 1.3. Given a proposed raise drill diameter and a rock mass of a certain range of QR 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 \( R = 1 - P(f) \times 100\% \)), for the range of raise bored diameters and rock mass qualities is presented as Figure 15.

![Figure 15 Probabilities of Failure Chart](image)

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 I. These provide guidelines for other raise drill shafts.

<table>
<thead>
<tr>
<th>Excavation Type</th>
<th>Service Life (Years)</th>
<th>Reliability R (%)</th>
<th>Probability of Failure P(f)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unlined hoisting Shaft</td>
<td>&gt;15</td>
<td>99</td>
<td>0.01</td>
</tr>
<tr>
<td>Ventilation Shaft</td>
<td>10</td>
<td>95</td>
<td>0.05</td>
</tr>
<tr>
<td>Ore Pass</td>
<td>&gt;2</td>
<td>85</td>
<td>0.15</td>
</tr>
<tr>
<td>Ore Pass</td>
<td>1</td>
<td>75</td>
<td>0.25</td>
</tr>
</tbody>
</table>

Table 1
Suggested acceptability of risk for various raise drill shafts
Conclusion

A method of quantifying the geotechnical risk associated with a raise drill or shaft bore shaft, is presented above, and based on shaft diameter and a raise drill rock quality index, QR.

The approach outlined provides 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 XV does not replace classical analysis as a means of evaluating the incidence and stability of potential failure wedges, but 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 associated with a proposed raise or shaft.

In many cases adverse ground conditions can be treated by cement grouting prior to raise drilling, or alternatively, advanced planning can be done to carry out support works directly after raise drilling.

Risks and the Control Thereof

One of the bigger risks in the shaft boring method is the potential scaling and deterioration of the center core pilot hole and the other to ensure the center core pilot hole remains open during the shaft boring.

To manage these factors the risks need to be managed and engineered to ensure success.

CONVENTIONAL VERTICAL BLIND SHAFT SINKING

Conventional blind shaft sinking using drill and blast techniques has been practiced for as long as underground mining has taken place.

Various shaft sinking methods are being used and these being:

- Hand held drilling of the bottom with nominally 2.0 meter advance per blast;
- Jumbo drilling of the bottom with either pneumatic or electro-hydraulic drifters with advance per blast of up to 6.0 meters;
- Mucking with an Eimco 630 type loader into a kibble;
- Mucking with a cryderman type clam system into a kibble;
- Mucking with a cactus grab type lashing unit into a kibble;
- Concurrent shaft concrete lining from the sinking stage above.

Rock is hoisted to surface or the bank elevation therefore not interfering with other rock hoisting operations. Bottom access is therefore not necessary and this is the method to follow where a shaft is sunk in green fields operations.

Large winding facilities are generally required to hoist the rock from the shaft bottom as well as a relatively large stage winder installation as a large stage has to be supported from such a winder, especially with the cactus grab cleaning method.

Shafts are generally equipped on completion of a sink to shaft bottom unless a cryderman type cleaning method is used, which supports concurrent equipping of a shaft with the sinking. A smaller stage winder is required with this cleaning method.

Blind sink operations are generally done with shafts of diameters of 4.5 meters and more. Advance per blasts will vary and advances per day will generally average around 3.5 meters to 4.5 meters depending on the depth of shaft and diameter.
The deepest one lift blind vertical shaft sunk to date has been the South Deep shaft in South Africa to a depth of some 2963 meters below collar.

Blind sink shafts can be sunk from very shallow to very deep depending on needs as well as to any diameters.

### PROS AND CONS OF CONVENTIONAL VERTICAL BLIND SINK SHAFTS COMPARED TO SHAFT BORED SHAFTS

<table>
<thead>
<tr>
<th>Comparison Items</th>
<th>Conventional Blind Sink</th>
<th>Shaft Bore</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Depth Restrictions</td>
<td>None</td>
<td>Competitively economical from 600m</td>
</tr>
<tr>
<td>2. Diameter restrictions</td>
<td>None</td>
<td>4.5m to 8.5m in diameter</td>
</tr>
<tr>
<td>3. Speed of sink</td>
<td>Faster up to 600m</td>
<td>Faster from 600m onwards</td>
</tr>
<tr>
<td>4. Blasting operations</td>
<td>All sinking</td>
<td>None</td>
</tr>
<tr>
<td>5. Need bottom access</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>6. Lining thickness</td>
<td>Thicker</td>
<td>Thinner</td>
</tr>
<tr>
<td>7. Safety aspects</td>
<td>Poorer</td>
<td>Best</td>
</tr>
<tr>
<td>8. Stage requirement</td>
<td>Large</td>
<td>Small</td>
</tr>
<tr>
<td>9. Kibble hoist requirement</td>
<td>Large hoist for rock &amp; material</td>
<td>Small hoist for men &amp; material only</td>
</tr>
<tr>
<td>10. Stage hoist</td>
<td>Large</td>
<td>Smaller</td>
</tr>
<tr>
<td>11. Sinking crew size</td>
<td>Larger</td>
<td>Smaller</td>
</tr>
</tbody>
</table>

Shaft boring becomes an economical option from depths of around 600 meters and deeper and at that point becomes cheaper and faster and can be bored to great depths.

Raise drilling fills the gap between a very small shaft and a larger shaft and is the fastest means of sinking a shaft provided bottom access is available.

Every technique has it’s place in the business and the pros and cons must be weighed up against each other before a final decision is made as to the required method of sinking.

### CONCLUSION

The mining industry's requirement for safe, rapid and economical mine development is met by the mechanical large diameter raise drilling and shaft boring 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. Raise drilling to depths exceeding 1000 meters and at diameters of up to 6 meters, is no longer uncommon. The method continues to be developed to cover an increasingly wide range of circumstances. The improvement made in directional drilling now enables hoisting shafts to be raise drilled, either in one pass or in combination with the V-mole.

By using the systematic risk assessment developed by A McCracken 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 raise drilling and shaft boring techniques have been proven in the execution of more than 50 projects throughout the world, with an accumulated depth of 21,000 meters and in a wide variety of rock types.

“Using alternative scenarios, the future literally becomes a matter of choice, not chance” - (Wolfgang Grukke)

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