MECHANISED MINE DEVELOPMENT UTILISING ROCK CUTTING AND BORING THROUGH RAISE AND BLIND BORING TECHNIQUES

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SYNOPSIS

The mechanisation of mine development is becoming increasingly important in our South African and Southern African mines with increased emphasis on safe and efficient mining.

Raise, blind and shaft boring offer mechanised solutions for excavations such as:-

- reef raises
- stope boxholes and shaft ore passes
- ventilation passes and shafts
- chairlifts
- large vertical hoisting shafts (in excess of 1200 metres in depth)
- angled hoisting shafts (from small to large diameter bored holes)
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These techniques will be discussed with reference to relevant applications and the author's comparison between conventional drill and blast techniques.

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1. INTRODUCTION

Issues of safety, economy, availability of skilled labour, as well as international competition emphasize the need for mechanised mine development.

Appropriate mechanisation suited to the circumstances at hand should be considered when selecting an excavation method.

Mechanisation includes mechanized drill, blast, support and cleaning methods, generally for flat to 10° inclined or declined excavations in Southern African mines, with special methods and equipment for steeper inclined/declined excavations. A drill and blast method offers greater flexibility than raise and blind boring techniques although each has its own pro's and con's.

2. CURRENT TECHNIQUES

FLAT DIPPING TO STEEP DIPPING TUNNELLING AND DEVELOPMENT

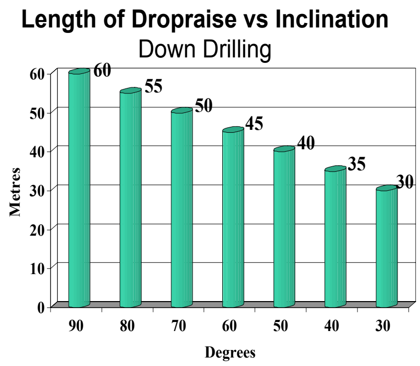
2.1 Drill and blast mechanised tunnelling and development

2.1.1 Drop raising

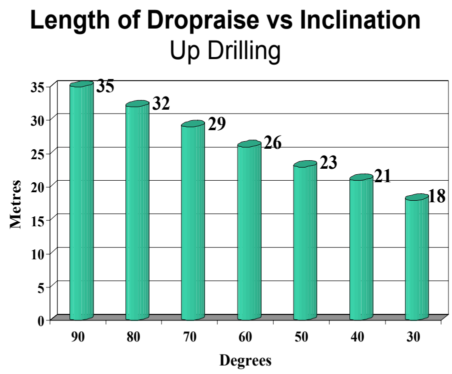
Drop raising, also known as "longhole raise blasting" or "upsidedown raising", is an excavation which is completely pre-drilled over its full length, then charged from the top, or bottom, and finally blasted from the bottom in practical lengths for an effective advance per blast.

Drop raising is commonly used world-wide in the development of rock and ventilation passes over a length of generally up to 60m in the vertical mode and around 15m in an almost flat mode (Refer graph 1 and 2 – Inclination and length matrix).

Graph 1



Graph 2



Drop raising offers a safe method of excavation at relatively economic cost. Major advantages of this method include not exposing people to the dangers of entering a pass from underneath, and, the ability to blast short passes of up to 10m in one blast.

Some additional important advantages are:-

Safety	The raise needs never to be entered once blasting commences, thus hazards posed by falls of ground, fumes, poor working conditions etc. are avoided.
Speed	Drilling of the raise is much faster than handheld operations. Once drilling has been completed, blasting can take place without the interruptions of making safe and drilling the next round.
Economy	The inside of the raise does not need to be equipped; thereby eliminating that cost. Improved safety and speed result in early availability of the raise.

DTH Drop Raise Drillrig

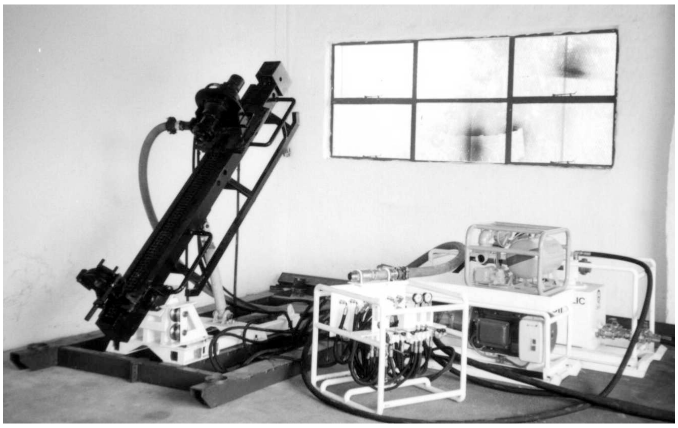


Figure 1

2.1.2 Alimak or mono-rail raising

Alimak raising makes use of a rack and pinion type system for the transportation of people into a pass with normal drill and blast methods. This method is widely used in Canada but has not found much favour in South Africa.

It is a relatively fast method and can be used in excavations in excess of 200m in length. A further advantage is that support components can be installed as one develops.

The Alimak method offers solutions in the development of reef raises, boxholes, ventilation passes, shafts, etc. at practical diameters ranging from ±1,8m to 6m.

2.1.3 Conventional vertical shaft sinking

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

Various shaft sinking methods are being used:-

- Handheld drilling of the bottom with a nominal 2.0 metre advance per blast
- Jumbo drilling of the bottom using either pneumatic or electro-hydraulic drifters with advance per blast of up to 6.0 metres
- 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, not interfering therefore with other rock hoisting operations. Bottom access becomes unnecessary. This, then, is the appropriate method where a shaft is sunk in green fields operations.

Large winding facilities are usually required to hoist the rock from the shaft bottom. A large stage winder installation is hence, a given, especially with cactus grab cleaning.

Shafts are frequently 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 necessary in this cleaning method.

Blind sink operations are generally done when sinking shafts of 4.5 metres in diameter and more. Advances per blast will vary and advances per day will average around 3.5 metres to 4.5 metres, depending on the depth of shaft and its 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 2 991 metres below collar.

Blind sink shafts can be sunk from very shallow to very deep, and to any diameter, depending on the requirement.

2.2 Rock cutting and boring

2.2.1 Raise boring

Raise boring has been commonly used in the mining industry since 1968 for the mechanical cutting of excavations to various diameters and lengths, ranging from 0,7m in diameter to 7,1m and up to 1260m in length.

Murray & Roberts Cementation has been involved in raise boring contracting since 1978 and has become the world's largest raise boring contractor. Murray & Roberts Cementation is considered a leader in the field of large diameter raise boring. The company operates a total of 41 raise drills, which include 4 Wirth HG 330 SP type machines; these being some of the largest raise drills ever manufactured in the world. This fleet has been extended to include one 123R, as well as two 103R machines.

Raise borers can be used in various modes of operation, the modes most often used are:-

- Conventional pilot drilling
- Conventional upreaming of vertical and inclined holes
- Down boring with a pre-drilled pilot hole
- Blind up boring

- Directional piloting and raise boring used in conjunction with a shaft boring machine (V-mole), for the drilling and support of a large diameter shaft.

Conventional Up-reaming of Pilot Holes

On completion of pilot drilling; and at such time as the pilot hole breaks lower excavation; a reaming head is fitted to the end of the drill string, rotated and reamed back. The size of the reaming heads range between 0,7 metres and 7,1 metre in diameter.

It is a safe, efficient and cost-effective method of making holes through different geological formations using powerful machines, high strength drill string and reliable heads. The maximum loading capacity of the drill string determines the diameter as well as the length of the shaft. The loading is dynamic and only approximately calculable because tensile, torsional and bending stresses overlap. See Figure 2

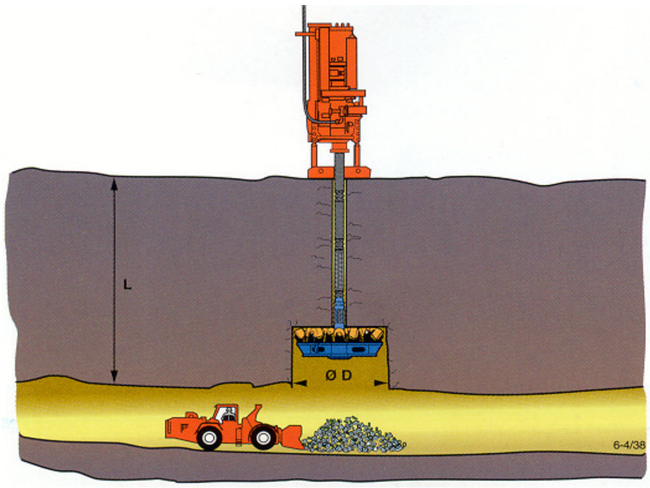
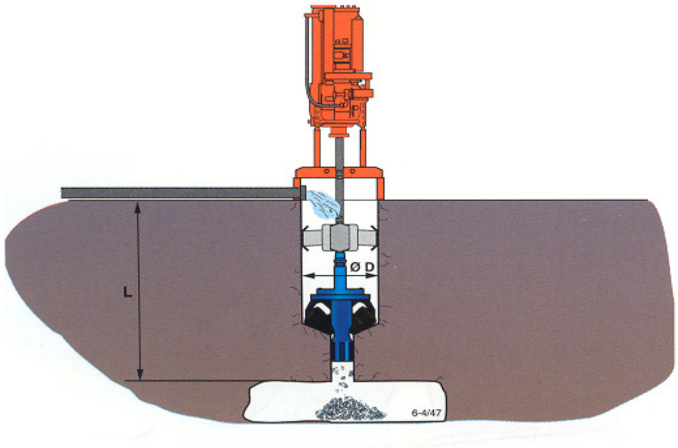


Figure 2

Down Boring with a Pre-drilled pilot hole

In this case an oversized 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 oversized pilot hole to the bottom of the hole where they are removed. In the case of smaller holes, cutter thrust is provided by the machine 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 often used as the risk of blocking the pilot hole and creating mud rushes at the bottom of the hole is too high.
See Figure 3



Downwards boring

Figure 3

Directional Pilot Drilling

Directional pilot drilling is costly and therefore only used in instances 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 regularly been achieved recently.

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.

Table 1 typically quantifies the capabilities of the various raise bore machines commonly available in the market.

Raise boring is more and more becoming an economical means of excavating small to large holes with great benefits over increased lengths.

Recent Achievements :-

Murray & Roberts Cementation currently holds world records and can boast the following achievements: -

- Largest diameter shaft raise drilled to 7.1 metres in diameter and 178 metres of vertical depth at Sasol Coal's Secunda Collieries' Bosjespruit Mine. (See Figure 4)

Figure 4 (7.1 Metre Reamer Head)

- Longest vertical hole reamed to 1.83 metres in diameter and 1260 metres deep at the Prismulde Project, Germany.
- At Kloof Gold Mine South Africa, a 1 100 metre deep, 4.1 metre diameter hole was drilled through the hardest lava rock formation with an UCS between 600 and 750 Mpa.
- Longest inclined raise drilled hole to 3.5 metres in diameter and 755 metres deep at BCL in Botswana.
- Deepest shaft V-mole bored in South Africa to 6.5 metres in diameter and 972 metres deep at Oryx Gold Mine.
- Deepest shaft V-mole bored at Prismulde Germany to 7.8 metres in diameter and 1260 metres deep by Thyssen Schachtbau of Germany
- Largest diameter V-mole shaft bored in hard rock to 7.1 metres in diameter and 785 metres deep at Alp Transit, St. Gotthard, Sedrun, Switzerland.
- At Impala Platinum Mine South Africa, Murray & Roberts Cementation drilled a 1 050 metre long, 5.1 metre diameter raise drill hole through norites with RVDS with 0.05 % accuracy.
- At Sedrun in Switzerland, a 785 metre long 1.83 metre diameter hole was drilled with RVDS with 0.035 % accuracy i.e. 280 mm deviation
- At Moab Khotsong in South Africa, a 360 metre long, 3.8 metre diameter hole was drilled with RVDS with 0.063 % accuracy i.e. 223 mm deviation
- At Prismulde in Germany, a 1 260 metre long, 1.83 metre diameter hole was drilled with down-the-hole motor measuring 0.04 % accuracy i.e. 450 mm deviation
- At Impala Platinum Mine South Africa, a 1 090 metre long, 5.1 metre diameter hole was drilled through norites.

Advantages are:-

- No in-hole ventilation system required.
- Very safe as few people involved.
- Great speed of raise boring, provided the cuttings can be removed timeously.
- Accurate drilling to accuracies of 0,035% deviation.

- No blasting and thus no blasting related fractures.
- Cost effective, especially where time is of the essence.
- The drilling of long holes has now become the norm.

Disadvantages are:-

- Straight line drilling makes it a relatively inflexible method.
- Expensive on a direct Rand per metre cost.
- Limited to certain sizes and lengths.
- Generally requires fairly large raise bore machine cubbies.
- Fast drilling requires high tonnage chip removal.
- Requires reasonably stable ground conditions.
- Top and bottom access is required.

Some special areas of application are:-

- Low angle raise boring for applications such as:-
  - tabular orebody reef raises from 11° above the horizontal over lengths up to 220m @ typical diameters of 1.5 – 1.8m. This method is at least twice as fast as any other common method and very safe.

Figure 5 – 85R machine @ 34°

Figure 6 – 1,5m Ø hole @ 17_°

  - slot raising of relatively short holes on reef in steeply angled ore bodies 20 to 40m in length of typically 1.0 – 1.8m in diameter as a blasting breaking point.
- Low angle raise boring of excavations such as chairlifts, travelling ways, inclined shafts, rope raises etc. to name a few with lengths of up to 220m and diameters of up to 3,5m and inclinations ranging from 11° above the horizontal.

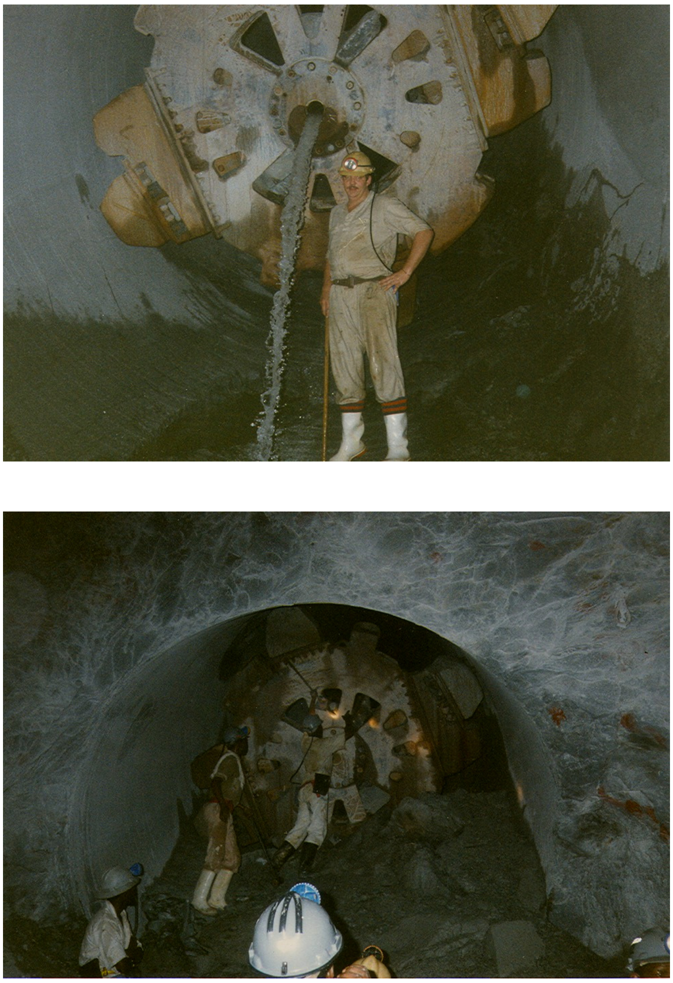


Figure 8 – 3,6m Ø hole @ 34°

2.2.2 Blind boring

Blind boring is the rock boring of a hole, typically of 1.5m in diameter from 34° from the horizontal to 90°.

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 they are deflected into muck cars. Blind boring has limited applications. See Figure 9

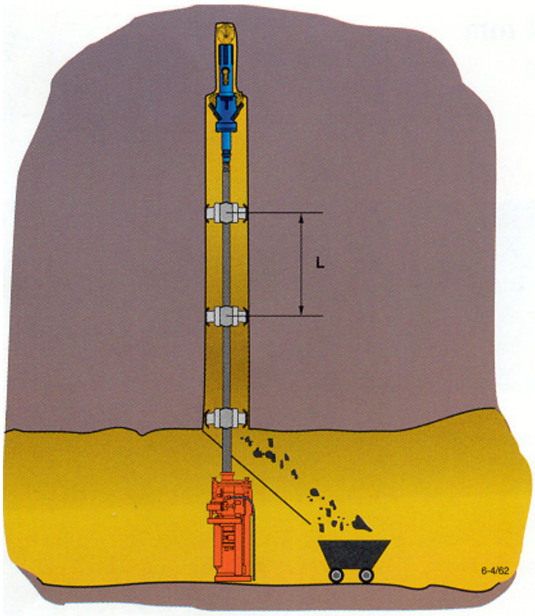


Figure 9

The longest known blind bore hole drilled to date, has been with a 53R over a distance of some 192m at a near vertical angle in 1989 at Anglogold Ashanti Tautona Mine.

The normal blind hole machines manufactured were generally designed around a maximum diameter of 1,5m and very seldom 1,8m.

The term, blind boring, came about as the early machine, a 52R, drilled its hole to full size of 1,5m without a pilot hole, because it has non-rotating drill pipe. One could comment today, that the term, blind boring, is not necessarily correct anymore, as the newer machines are now able to first pilot a hole then ream the hole.

2.2.3 Shaft boring

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

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

- relatively competent rock (unsupported center core to stand up)
- a reamed pilot hole between shaft head and shaft bottom of approximately 1.83 to 2.4 metres in diameter with sufficient verticality to serve as center core. During the boring operation the center core pilot hole is used to drop the reamed cuttings to the bottom of the new shaft and 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 guided by a laser beam down 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 instead becomes a factor of the ability to drill and ream a pilot hole to 1.83 metre in diameter. We know that the drilling of holes of 1 300 metres in depth is possible and has been done before. The next challenge will be to drill a 1.83 metre diameter hole over a continuous length/depth of more than 1 500 metres. The shaft depth is therefore unlimited as long as a center core pilot hole is possible.

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 and 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

In 1971, the first shaft boring machine was put into service in the coal mines in Germany by a consortium of specialist mining contractors, Deilmann-Haniel GmbH (Dortmund) and Thyssen Schachtbau GmbH.

Since 1989 , the company has gained operational experience in shaft boring using the V-mole shaft boring techniques. To date, four major shaft projects have been completed viz.:-

- 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
- 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 shaft boring machine, better known as a V-mole.

Vertical shaft boring for ventilations shafts, as well as hoisting facilities have once again become a special shaft construction method in today's drive on safe production. (Refer figure 10)

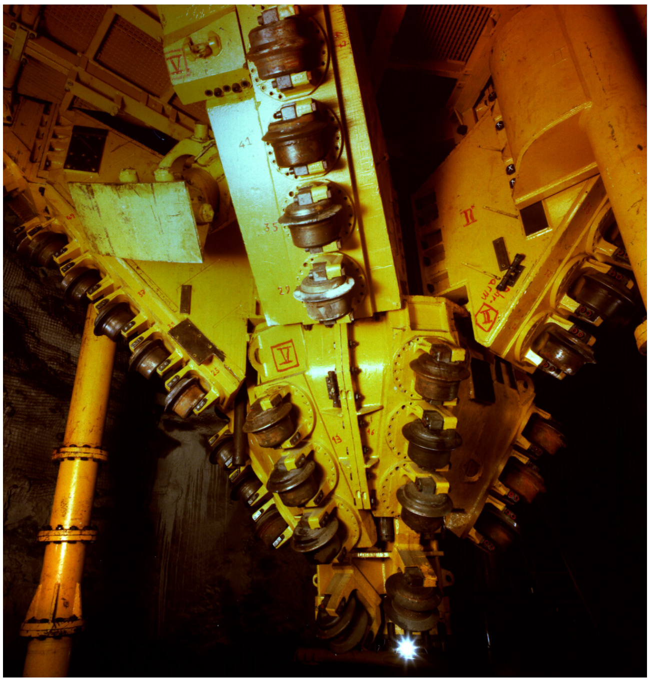


Figure 10 – V-Mole Machine

3. COMPARISON OF SIMILAR TECHNIQUES

3.1 Pros And Cons Of Conventional Vertical Blind Sink Shafts Compared with Shaft Bored Shafts

	Factors	**Conventional Blind Sink**	**Shaft Bore**
1	Depth restrictions	None	Competitively economical from 800 m
2	Diameter restrictions	None	4.5m to 8.5m in diameter
3	Speed of sink	Faster up to 800m	Faster from 800m onwards
4	Blasting operations	All sinking	None
5	Need bottom access	No	Yes
6	Lining thickness	Thicker	Thinner
7	Safety aspects	Poorer	Best
8	Stage requirement	Large	Small
9	Kibble hoist requirement	Large hoist for rock & material	Small hoist for men & material only
10	Stage hoist	Large	Smaller
11	Sinking crew size	Larger	Smaller

Shaft boring becomes an economical option from depths of around 800 metres 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 its place in the business and the pros and cons must be weighed up against each other before a final decision can be made on the optimal method of sinking.

A simplified table (refer Table 2) depicts the length/depth of holes/tunnels that could typically be drilled or excavated by the means listed as a guideline in choosing mining methods.

4. FUTURE CHALLENGES

The future requires more focus on and implementation of mechanised tunnelling, from the vertical to the horizontal, as well as in a range of sizes of excavations.

Orepass development by means of conventional handheld methods is fast becoming a thing of the past and will be replaced by drop raising and blind boring.

It is essential that the correct type of equipment be developed to suit the conventional South African gold and platinum mines.

Safety, economics, skilled labour and international competition will be the driving forces behind these developments.

5. SAFETY ASPECTS

Developing orepasses and reef raises at depths in excess of 3000 metres by conventional handheld means, can today be replaced by raise or blind boring methods.

Safety in our mining industry is paramount. To prevent injuries and deaths, we must mechanise our development and tunnelling operations. Fewer people to do the same work but less arduous work, will lead us to appropriate mechanisation in the mining industry.

6. CONCLUSION

The mining industry's requirement for safe, rapid and economical mine development is met by the mechanical large and small diameter raise drilling, blind boring and shaft boring methods described. The techniques provide 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 1 200 metres and at diameters of up to 7 metres, is no longer uncommon. The methods continue to be developed to cover an increasingly wide range of situations and conditions.

The capabilities and effectiveness of the raise drilling, blind boring and shaft boring techniques have been proven in the execution of projects throughout the world since 1968 and in a wide variety of rock types.

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

7. ACKNOWLEDGEMENTS

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Table 1

COMAPRISON FOR INCLINED EXCAVATIONS								
metres	<30	30-45 <45	45-60 <60	60-90 <	90-200	200-400	400-700	700 >
TYPE INCLINED								
Hand held	√							
Drop raising	√	√						
Alimak		√	√	√	√			
Blind boring								
52R		√	√					
53R	√	√	√	√	√			
33/34R	√		√					
Other	√	√						
65R	√	√	√	√	√			
Raise boring								
43R	√	√						
53R	√	√	√	√	√			
6 Series/RBM 6			√	√	√			
7 Series/RBM 7			√	√	√			
8 Series			√	√	√	√		
9 Series					√	√	√	
10 Series					√	√	√	
12 Series					√	√	√	√
HG330					√	√	√	√
HG380					√	√	√	√

TYPICAL RAISE/BLIND BORE MACHINE CAPABILITY MATRIX AT 12 TON/CUTTER (THEORETICAL)													
COMMON MACHINE TYPE	24R	33/34R	43R	52R	53R	61R/65R/RBM 6	71/ 72R / RBM7	83/85R	97R	103R	123R	HG330	HG380
HOLE DIA.(m)													
0,7	60	60	250		350								
1,0	40	45	200		300	759	901	949	1187	1187	1774	1860	1828
1,2			150		250	651	824	899	1124	1124	1721	1808	1793
1,5			100	80	200	543	747	849	1061	1061	1668	1756	1760
1,8					165	435	669	796	995	995	1617	1704	1725
2,1						327	591	744	930	930	1565	1652	1689
2,4							513	692	865	865	1512	1600	1654
2,7							435	640	800	800	1461	1548	1619
3,1							425	634	793	793	1455	1542	1613
3,5								574	718	718	1395	1482	1578
3,8								520	650	650	1341	1428	1553
4,1								467	584	584	1287	1375	1474
4,5								405	506	506	1226	1313	1441
4,8								353	441	441	1175	1261	1406
5,1								298	373	373	1119	1207	1371
5,5								244	305	305	1067	1153	1338
5,8								195	244	244	1014	1102	1302
6,1									176	176	962	1050	1261
7,1											536	623	1032

Table 2