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The introduction of mechanical shaft drilling in the Gold Fields Group

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SYNOPSIS

The paper reviews the introduction of mechanical shaft drilling into the sinking of shafts in the Gold Fields Group. A comparison is made between the operating costs of the drilling rig and those of conventional hand-held machines, and it is concluded that, despite certain disadvantages, mechanical drilling is preferable.

SAMEVATTING

Die referaat gee 'n oorsig oor die invoering van meganiese skagboorwerk vir die sink van skagte in die Gold Fields-groep. Daar word 'n vergelyking getref tussen die bedryfskoste van die boorinstallasie en dié van konvensionele handmasjiene en die gevolgtrekking wat gemaak word, is dat meganiese boorwerk, ten spyte van sekere nadele, verkieslik is.

Introduction

Inflationary pressure, coupled with a drive to improve productivity, has forced the mining industry to seek cheaper and faster methods of conducting the activities in which it is involved. In the past, however, the availability of low-cost unskilled labour has tended to hinder the introduction of mechanized mining systems in all facets of mining activity. However, a severe shortage of labour in the early 1970s gave impetus to the development and introduction of 'drilling jumbos' and other mechanical equipment for tunnelling operations.

Before that time, significant advances had been made in shaft sinking with the effective introduction of the Cactus Grab in No. 3 Shaft at Vlakfontein Gold Mine and the utilization of concurrent sinking and lining techniques. The rate of sinking increased dramatically over the next decade, and a number of shaft-sinking records were established. However, except for the use of larger and more efficient machines, little or no significant advance was made in drilling activity. The machine crews still constituted approximately 53 per cent of the labour force employed in the sinking activity in shafts where hand-held rock drills were utilized.

The effective introduction of drilling jumbos in development, coupled with the shortage of labour, encouraged Gold Fields to focus attention on shaft drilling. Early in 1974, the Company approached Delfos & Atlas Copco, asking them to produce an effective system that could be employed in drilling the shaft bottom. The system to be developed was to be capable of drilling the full round in at least the same time as a normal machine crew would perform the activity, and to result in a reduction in the labour complement.

Delfos & Atlas Copco, employing their Italian company because of its expertise in this field, produced a number of schemes over the next three years. In general, the proposed systems were not acceptable as they were suspended from the sinking stage. The obvious shortcomings of the proposals (restricting stage mobility during the drilling operation) influenced the final parameters for the design of a drill rig suitable for the drilling of the shaft bottom.

The final parameters were as follows:

(i) The unit was to be capable of being opened 'like an umbrella', and was to be free-standing on the shaft bottom.
(ii) The unit in the closed position was to be capable of being passed through the stage.
(iii) The overall mass of the unit was dependent on the size of shaft in which it was to be employed, but should be limited to the hoisting capacity of the kibble winder.
(iv) The unit was to be capable of drilling a shaft round in 1½ to 2 hours and also be suitable for cover drilling.

The year 1977 saw the end of the labour shortage and, although efficient labour utilization was of prime importance and the problems of spiralling costs still existed, the pressure on the development of equipment was replaced by the attitude that the introduction of any mechanized equipment had to be economically viable. The attitude that the labour employed on the sinking of shafts would remain constant whether drilling jumbos were employed or not owing to the requirements of labour for other activities was the restricting factor to the introduction of mechanized drilling at that time.

A large number of shafts were sunk during the next few years on various mines in the Group, but it was not until Shaft Sinkers, who were contracted to sink the No. 4 Ventilation Shaft at Kloof, introduced a six-boom drilling jumbo for use in that shaft that the interest in drilling jumbos within the Gold Fields Group was rekindled. A second-hand, fully reconditioned drill rig was pur-

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chased from Shaft Sinkers in 1984 for use in the sinking of No. 4 Shaft at Kloof. The rig was designed and manufactured by Shaft Sinkers, and comprised 6 hydraulic booms independently mounted on a centre column containing the hydraulic- and lubricating-oil reservoirs. The centre column was mounted on a base in which the pneumatically operated hydraulic power packs were situated.

The hydraulic booms were fitted with pneumatic drifters and Gardner Denver PR 123-17J rock drills. The rig was capable of drilling the shaft bottom in shafts from a minimum of 1 m in diameter to a maximum cut size of 9,3 m, and was suitable for passing through a stage-kibble opening 2,11 m in diameter. The total mass of the rig was 14 t.

The results achieved with this rig were encouraging, the assessed advantages and disadvantages being as follows.

Advantages

(i) an effective reduction in labour,
(ii) reduction of overbreak and thus a saving in concrete cost,
(iii) reduction in cover-drilling time.

Disadvantages

(i) additional skilled labour (artisans) was required,
(ii) with only twelve operators required per shift, additional labour would be required for station development if mechanized station-development equipment was not employed (the boom rig is capable of cutting station brows effectively, but is generally restricted to the shaft barrel),
(iii) a complete breakdown of the hydraulic system of the rig could cause expensive delays.

Modern Drill Rigs in the Gold Fields Group

In 1985, with the announcement of the development of the Leeudoorn Division of the Kloof Gold Mining Co. Ltd, agreement was reached between Gold Fields, Shaft Sinkers, and Delfos & Atlas Copco that the first of a new generation of shaft-drilling rigs would be purchased for use in the shaft-sinking programme at No. 1 Shaft. This generation of drill drig was developed and manufactured by Delfos & Atlas Copco. The design was based on Shaft Sinkers' specifications and the experience gained by Shaft Sinkers and Gold Fields personnel at Kloof No. 4 Shaft. The rig was manufactured and delivered to Leeudoorn in 1986, and has given relatively trouble-free performance to date.

The drill rig, shown photographically in Figs. 1 and 2, and diagrammatically in Figs. 3 and 4, comprises seven hydraulically operated booms, each fitted with an Atlas Copco BMH 153 feed beam and a COP 932 pneumatic rockdrill.

The seven booms are mounted on a centre column together with compressed air and water manifolds. The centre column is supported on a base containing pneumatically operated hydraulic power packs. lubricating-

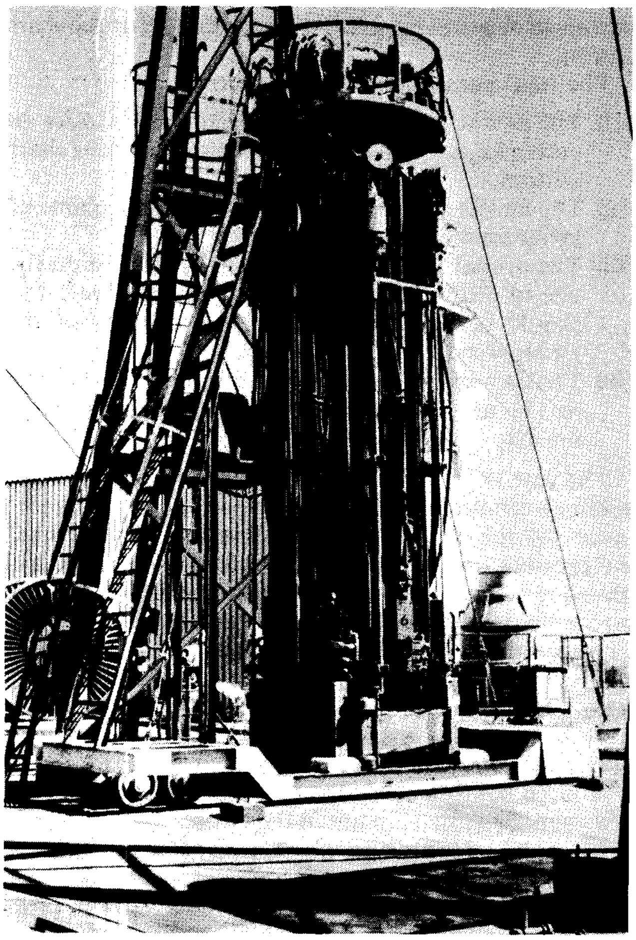

Fig. 1—The drilling rig in a closed position

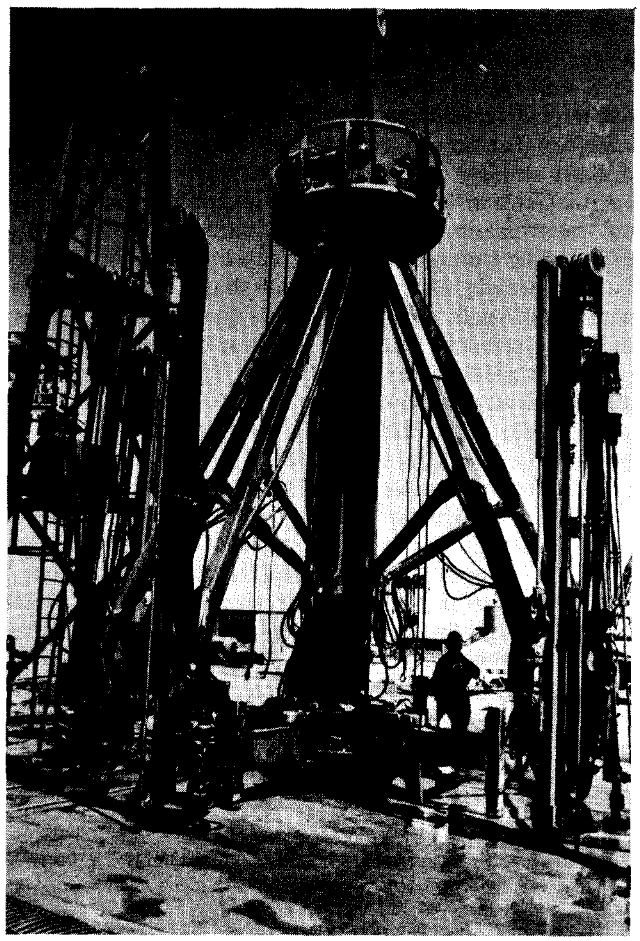

Fig. 2—The drilling rig opened like an umbrella

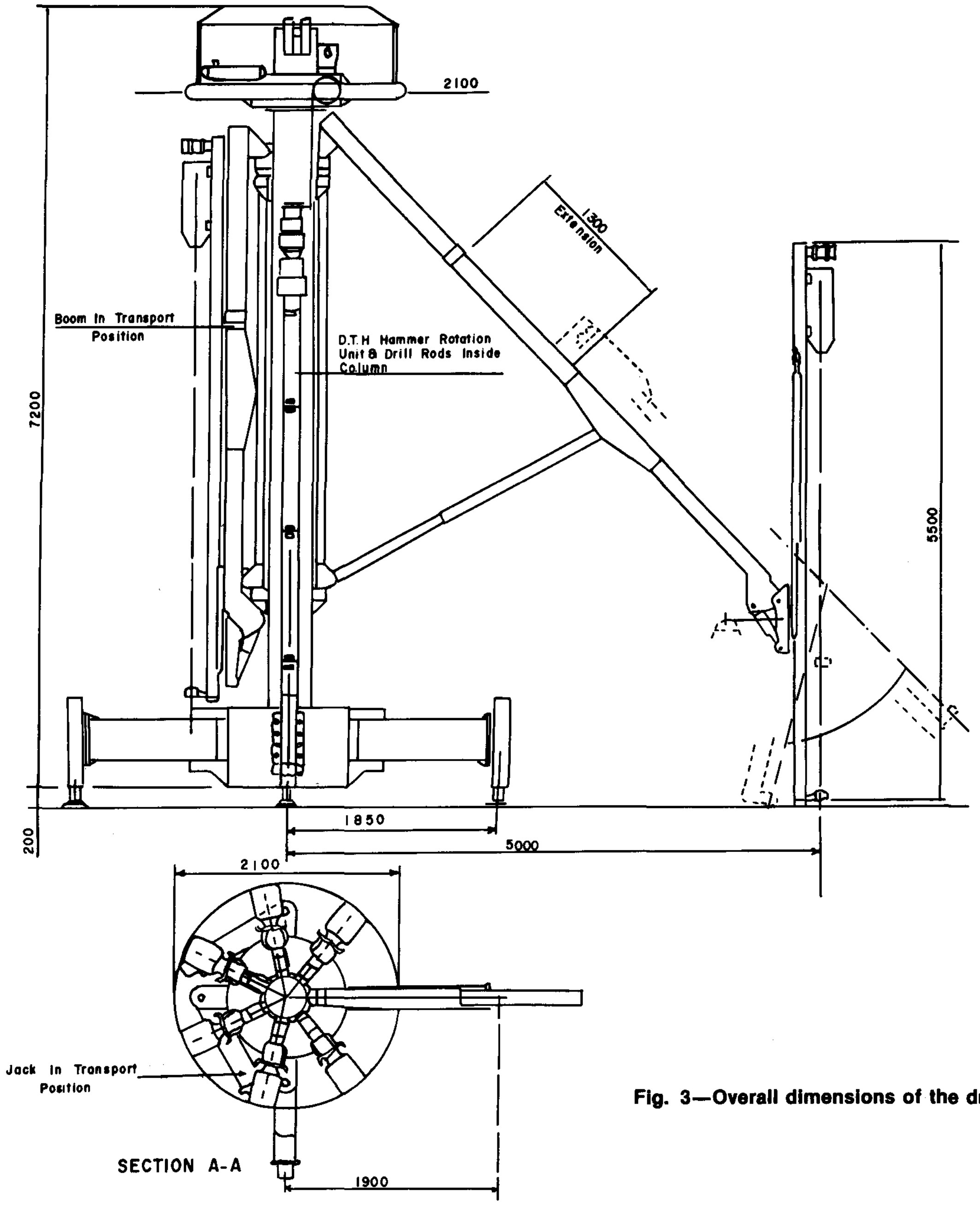

Fig. 3—Overall dimensions of the drilling rig

and hydraulic-oil reservoirs, and four pivoted extendable arms fitted with hydraulic stabilizing jacks for levelling. A down-the-hole hammer system comprising an Atlas Copco rotation head and COP 62 hammer suitable for drilling a 140 mm diameter cut hole is mounted in the centre column, as shown in Fig. 5.

The entire rig in the collapsed condition is capable of passing through a kibble opening of 2,186 m diameter, and has a length of 7,2 m. A second, identical rig manufactured by Delfos & Atlas Copco has been in operation in the No. 2 Shaft of the Northam Platinum Mine since August 1987.

Description of the Rig at Leeudoorn

Technical Specifications

The overall dimensions of the 7-boom rig with down-the-hole hammer are shown in Fig. 3, the complete rig weighing some 14 000 kg. The pneumatic/hydraulic power packs are powered by Standard Atlas Copco Vane Motors. Detailed specifications are given in the Addendum.

The BMH 153 feed beam fitted to each boom, which is operated by hydraulic cylinders, has a cross-sectional profile that gives good bending and torsional resistance, and is manufactured from wear-resistant aluminium. The rock-drill cradle is guided by easily replaceable hardened-steel wear components. The feed movement is transferred from a hydraulic cylinder to the cradle via two wire ropes.

The COP rock-drill machines feature oil-free compressed air that is utilized in the impact mechanism and rotating elements lubricated by an oil–air mix passing through a separate duct system, resulting in virtually oil-free exhaust from the machine. The machine design in-

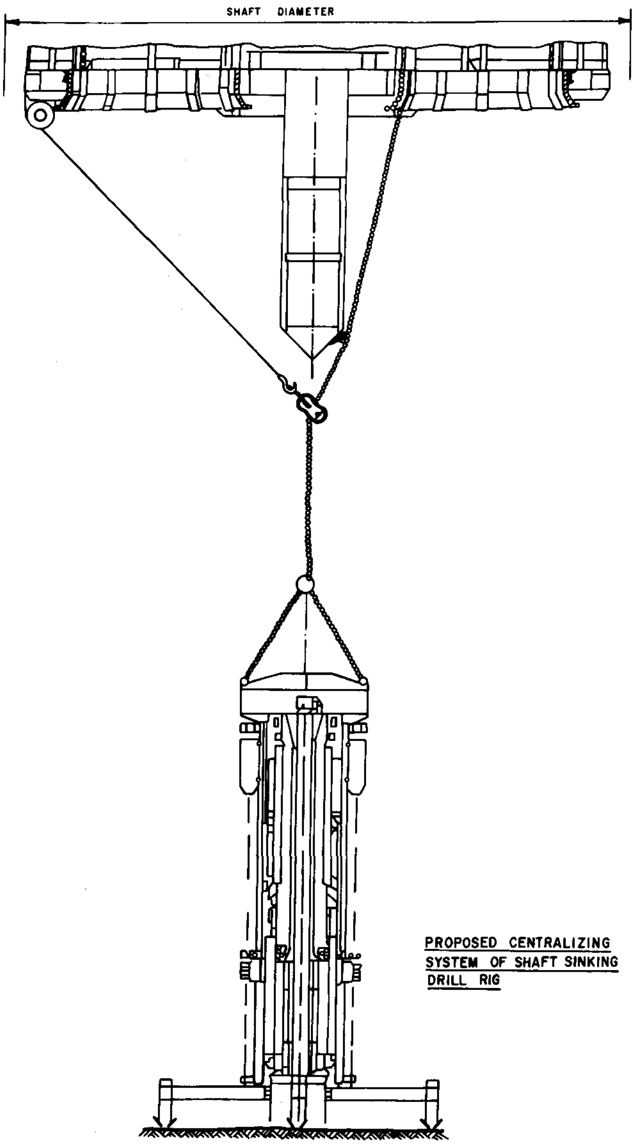

Fig. 4—The centralizing system of the drilling rig

cludes an effective built-in silencing system.

The booms are fitted with hydraulic locks (check valves) to prevent creep or collapse in the event of failure of a hydraulic hose. The boom lift, extension, inclination, feed extension, and rock-drill movements are operated hydraulically. The boom rotation is done manually. The rock-drill and boom controls are swivel-mounted at the lower end of each feed beam.

The four stabilizing jacks fitted to the base are operated hydraulically, the controls being situated on the base of the rig.

Fig. 6 shows the area of the shaft bottom covered by the seven booms, and Fig. 7 the inclination of the drill holes possible for blasthole drilling.

Surface Handling

The rig is transported to and from the shaft by rail (750 mm gauge) on an electrically driven car. Transportation takes place with the rig in a vertical position, which ensures little or no damage to hydraulic and pneumatic pipe lines. The rig is parked under a crane gantry specially

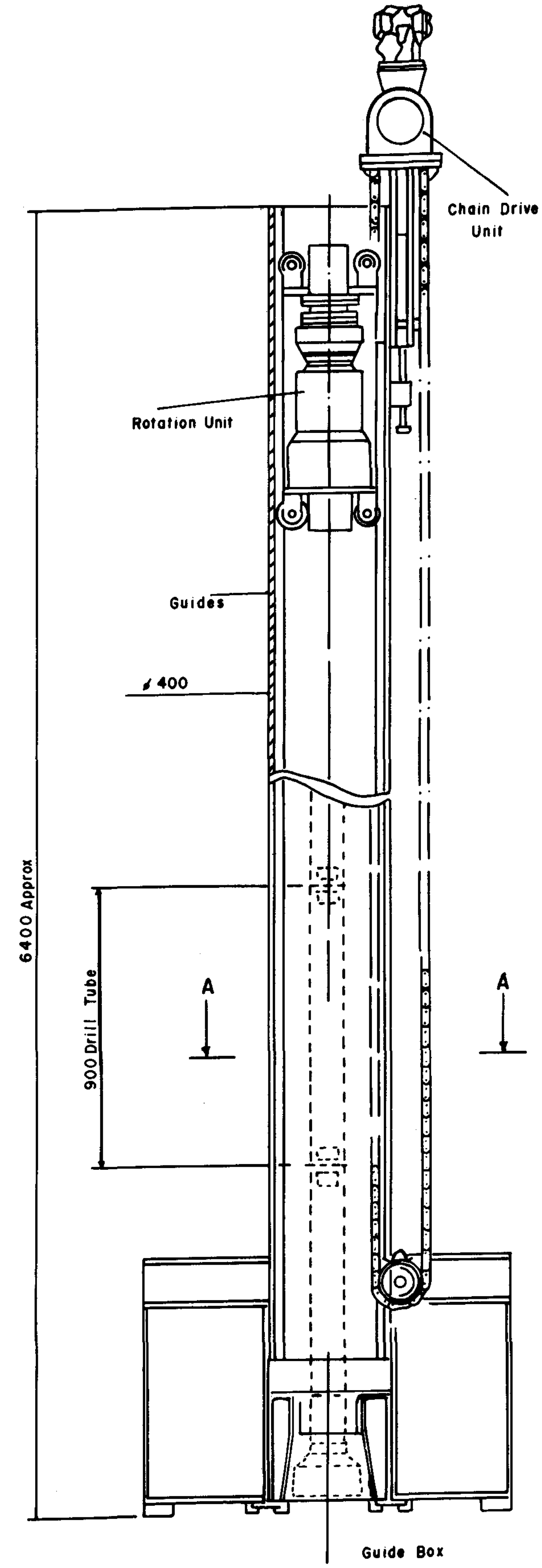

Fig. 5—The general arrangement of the chain feed and guide in the drilling rig

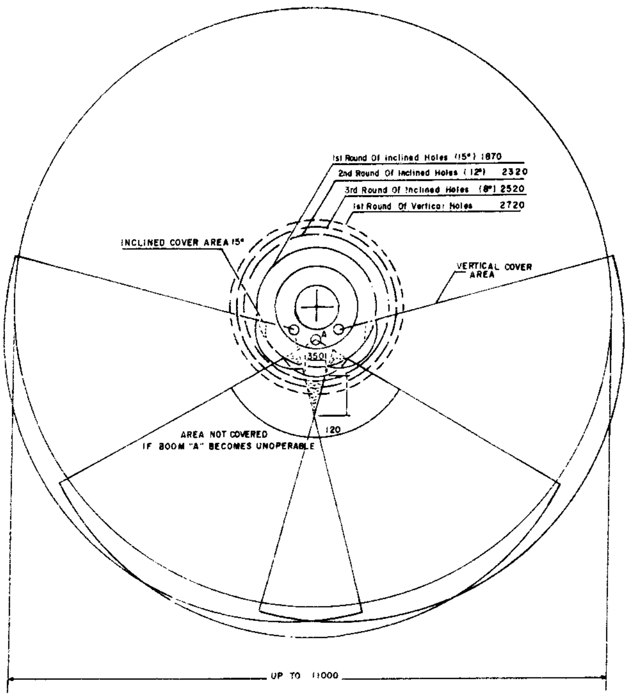

Fig. 6—The cover area of the drilling rig

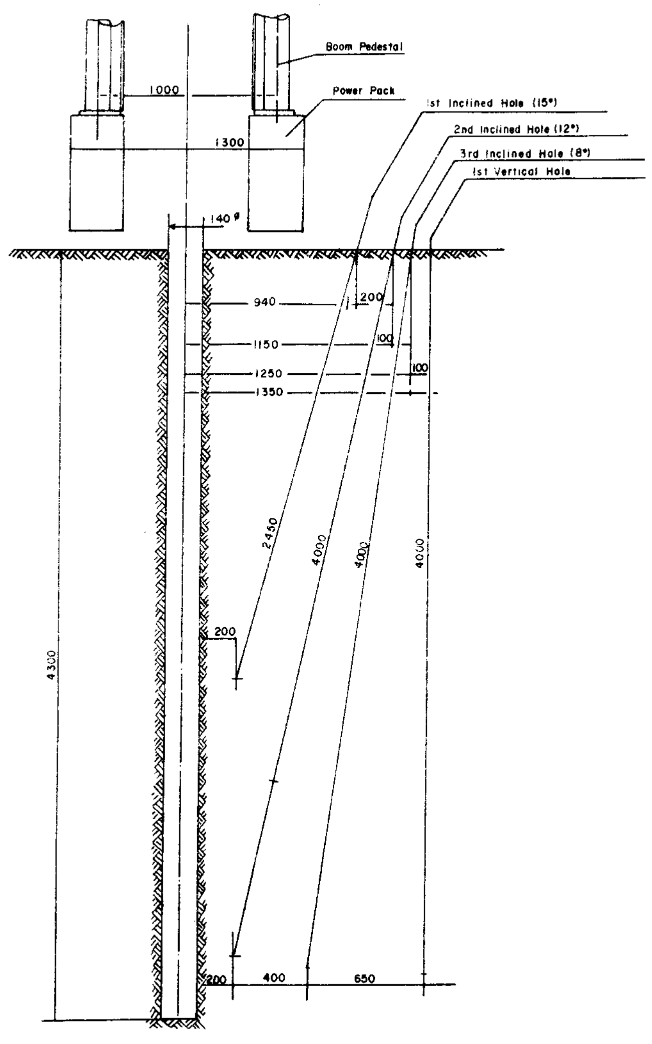

Fig. 7—The drilling pattern of 9- and 8-boom 'central column' drilling rigs

designed for the purpose of removing it from the transport car. This enables maintenance to be carried out with ease. The crane gantry is situated some 50 m from the shaft head.

Operation

The drilling rig is being used to sink a shaft of 9,15 m diameter to a depth of about 1900 m. During the early stages of the machine's use, only a few teething problems were experienced. However, these were quickly rectified with the assistance of the manufacturers. The use of the rig has resulted in the break after each blast being virtually perfectly round, with barrels showing right round the periphery of the shaft. Cover drilling is successfully carried out using the rig in its standard form.

Drilling Pattern

The drilling pattern or 'round' is shown in Fig. 8 and is made up of the following features:

Cut diameter of shaft 10,2 m
Number of blast-holes 148 holes 3,3 m in length
65 croppers of 45 mm diameter
83 inner of 54 mm diameter
Centre hole 140 mm in diameter

Note: Conventional drilling in a shaft of this diameter would have approximately 210 holes each of 50 mm diameter.

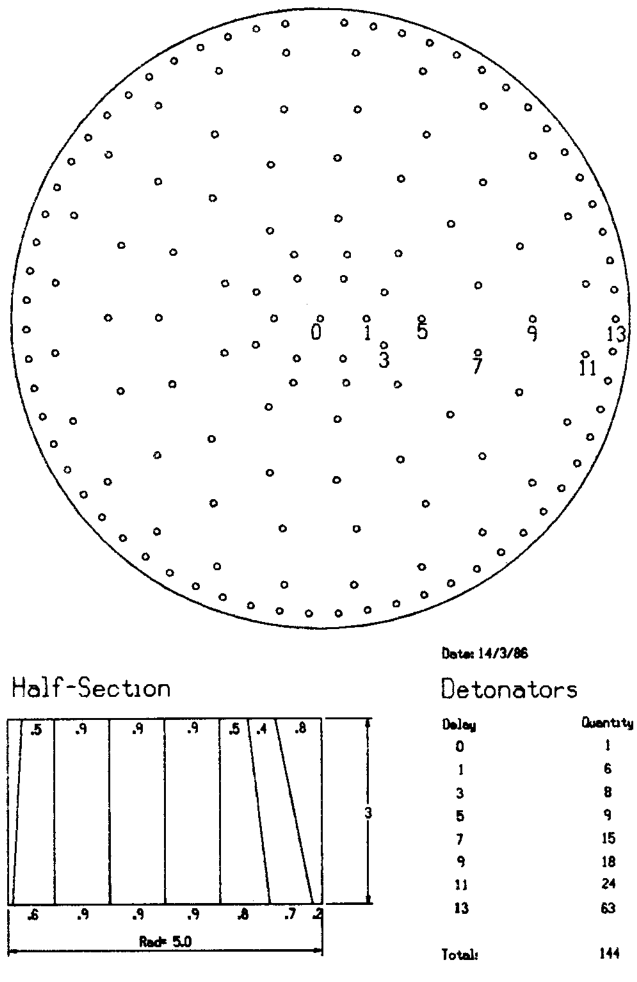

Fig. 8—The drilling pattern (scale 1/75) of the rig at Leeudoorn

Centre Hole

As previously noted, one of the features of the rig is its down-the-hole hammer drill of 140 mm diameter. The purpose of this device is to provide an effective breaking point to improve the accuracy and cleanness of the round. This is a departure from normal hand-drilling practice, which does not allow for the drilling of a hole of this diameter. During the early period of sinking with the rig, a breakdown resulted in the down-the-hole hammer being out of operation for approximately three weeks. This led to feelings of resistance by both the engineering and the mining personnel, particularly as acceptable results were being achieved without it. However, as sinking has progressed, the attitudes have changed, and the use of the down-the-hole hammer is posing no problems. Both the engineering and mining departments are now in favour of it. The feeling on Leeudoorn is that it *does* provide an effective breaking point, which is of great benefit, and that, given the choice, staff would request its inclusion as a design feature in future rigs.

Drilling Crew

The crew needed to operate the rig consists of 21 men per shift made up as follows:

1	sinker
1	sinker's helper
1	boom-rig fitter
2	fitter's assistants
2	down-the-hole operators
7	machine operators
7	machine assistants
21	Total

The same crew is used during cover drilling, which is carried out by use of the drilling rig.

Operating Statistics

The average advance per round is 3,1 m with holes drilled to a depth of 3,3 m. It takes 15 minutes to lower the rig and set it up on the shaft bottom. Drilling time for the 156 holes in a standard round is 2 hours. To remove the rig on completion of the drilling operation takes 25 minutes. The average cycle time, measured from blast to blast, is 10,5 hours, while the best cycle time achieved to date is 9 hours and 7 minutes.

The drilling of fourteen 45 m holes takes an average time of 30 hours. The best time for this operation was 17 hours 41 minutes.

The average rate of advance for the period September 1986 to March 1987 was 110 m per month. This rate includes the development of cable pockets at intervals of 280 m. The pockets are conventional 4 m by 3 m by 8 m L-ends.

Maintenance

The maintenance crew, which services and repairs the rig after each round, consists of a fitter and 2 assistants. Maintenance is done on surface. The first operation is to clean the rig with a high-pressure water-jet apparatus. Then the controls, motors, and operation of the hydraulic cylinders are tested to identify defects. Should any defective part be found, it is replaced. Particular attention is given to the hydraulic and pneumatic hoses. Any damaged hose is removed and replaced.

There are many hoses of different lengths on the rig. It has been found to be preferable to make up each hose as required, rather than to stock a large variety of hose lengths. Reels of hoses of different diameters are on hand, and connectors are attached with a crimping machine. The shank-adapter boxes on the rockdrills are carefully inspected to make sure that the drill shanks and water seals are in good order. The shank-adapter boxes are all inspected, and the seals and shanks are replaced when necessary.

After every 100 m advanced, all the drifters are stripped and overhauled completely. As spares are limited, this is carried out on a rotational basis.

Problems and Modifications

Very early in the life of the rig, hydraulic problems were encountered, the most severe of which was the failure of the main hydraulic pumps. Inspection revealed that severe cavitation was taking place within the pumps. The suction conditions were altered, and to date no further problems with cavitation have been experienced.

The first two months of sinking were plagued with the excessive breaking of shank adapters (4 per shift). The adapters were costing about R340 each. The design and supplier were changed, and the average life improved 40-fold.

The pressure of drilling water was found to be critical. Suitable valve arrangements have been installed to ensure that the water pressure at the drills is maintained at 1500 kPa.

The down-the-hole hammer failed twice during the early sinking period owing mainly to the inexperience of the crew. Since these problems have been sorted out, the down-the-hole hammer has functioned well.

During the first attempt to use the machine for cover drilling, extreme vibrations were set up within the machine. This resulted from the fact that the boom reaction pads could not be landed onto the shaft bottom because the grouted-in shut-off cocks were in their way. This problem was overcome by the making of special stools that are fitted to the shaft bottom and bridge the shut-off cocks. Full stability is now achieved during cover drilling.

The rig has been in use for almost a year now, and it can generally be stated that no problems exist.

Costs

Capital

Table I compares the capital costs associated with the rig with those for conventional hand-held machines.

TABLE I

COMPARISON OF CAPITAL COSTS

Drilling rig		Hand-held machines	
Rig	887 040	60 Seco S25 rock drills	72 300
Crane gantry	14 631	10 Seco S26 rock drills	235 000
Overhead hoist	22 268	Spares at 30% of cost	36 937
Spares (30% of cost)	266 112		
Transport car	9 500		
Total	R1 199 551	Total	R344 237

Drill Steel

Table II shows the costs of drill steel for normal blast-hole drilling based on 156 holes of 3,45 m per round. During the first four months, many problems were encountered with broken shank adapters. However, this problem was sorted out and, since then, the average cost per metre drilled has settled at R1,53.

TABLE II
COST OF DRILL STEEL FOR NORMAL BLAST-HOLE DRILLING WITH THE RIG

Month	Advance m	Cost R	Cost/metre drilled R
Sep. 86	93,4	162 116,63	11,13
Oct. 86	100,0	67 643,55	4,34
Nov. 86	129,3	11 208,64	0,56
Dec. 86	97,1	89 299,36	5,89
Jan. 87	136,2	30 239,97	1,42
Feb. 87	129,3	35 463,79	1,76
Mar. 87	82,8	17 580,11	1,36
Total	768,1	413 552,05	3,78

For conventional drilling, it is assumed that 2 m long by 25 mm hex by 38 mm gauge drill steel is used, that each drill can be sharpened six times, and that each rod drills four holes per shift. Then, each drill will drill as follows:

Depth = Number of sharpenings before discard × advance per hole × holes per shift
= 6 × 1,8 × 4
= 43,2 m.

Current cost for the above steel = R70,00
Therefore, cost per metre drilled = $\frac{70}{43,2}$
= R1,63.

It will be seen that, on the whole, the costs of the drill steel are comparable. The costs for the drilling of cover are thus not compared here.

Labour

The labour requirements of the drilling rig are compared with those of conventional hand-held machines in Table III.

TABLE III
LABOUR FOR DRILLING

Drilling rig		Hand-held drills	Variance
Skilled	35 + 8 = 43	38 + 8 = 46	–
Unskilled mining	230	412	+ 182
Unskilled engineering	44	38	−6
Total	317	496	+ 176

The extra unskilled mining labour used with hand-held drills consists of 91 machine operators and 91 machine assistants.

If the target monthly bonus is R2000 and drilling operators get a bonus of 12 per cent while the assistants get 10 per cent, the total savings per month achieved by the rig will be as follows:

R(64 682,80) + R(61 042,80) = R125 725,60.

However, the costs of the engineering labour would be higher:

	Monthly cost
3 Fitters	R10 500,00
3 Aides	2 439,36
3 Assistants	1 448,40
Total	R14 387,76

The total labour savings per month achieved by the drilling rig are

R125 725,60 − 14 387,76 = R111 335,84.

Excluded in the above comparisons is the cost of housing or accommodation.

Concrete

Owing to the fact that overbreak is considerably reduced when the drilling rig is used, there is a saving in the amount of concrete consumed.

During the period September 1986 to March 1987, the number of batches of concrete for a shaft depth of 774 m at a diameter of 9,15 m was 17 631.

Therefore batches per metre of shaft sunk = $\frac{17\,631}{774}$
= 22,78

Average cost per metre sunk = 67,50 × 0,75 × 22,78
= R1 153,19 per metre.

Each batch is 0,75 m^3 of concrete at R67,50 per cubic metre.

At Driefontein Gold Mining Co., where an identical shaft was sunk using hand-held machines, 35 217 batches of concrete were used to line 1464 m of shaft.

Therefore average batches of concrete per metre sunk = $\frac{35\,217}{1\,464}$
= 24,06

Therefore, average cost per metre sunk = 67,50 × 75 × 24,06
= R1 217,80.

Operating Costs (Spares)

From September 1986 to March 1987, the total operating costs of the drilling rig amounted to R392 463,00 for 774 m.

Therefore, the operating cost = $\frac{392\,463}{724}$
= R507,06 per metre advanced.

As no recent comparative costs are available for hand-held drills, the existing cost per metre drilled in the Group is taken as a comparison, i.e. R0,63 per metre advanced.

Therefore, 156 holes per round × 0,63 = R98,28 per metre advanced.

Cost summary

A cost summary is given in Table IV for a 2000 m shaft of 9,15 m diameter using hand-held and mechanical drilling. All the costs are given on the basis of cost per metre advanced.

TABLE IV
COST SUMMARY

	Hand-held drills R	Drilling rig R
Capital outlay	172,37	599,75
Drill steel	254,28	238,68
Labour	1 249,42	130,78
Concrete	1 217,80	1 153,19
Operating costs	98,28	507,06
Total	2 992,16	2 629,46

As shown in Fig. 9, in which these costs are plotted, despite the high capital cost of the drilling rig, its total costs break even with conventional methods at a depth just below 1200 m. When it is considered that this machine can be re-used in a future shaft at a possible overhaul cost of R700 000, the resulting graph is as shown in Fig. 10. It will be seen that the break-even point with hand-held machines now occurs at 700 m.

Conclusions

The cost analysis shows that, despite the high capital cost, a drilling rig is economically viable and costs less than conventional hand-held machines. There are also advantages in the use of the drilling rig, which are as follows.

(1) For shafts deeper than about 1200 m, the drilling rig is cheaper than conventional hand-held machines.
(2) The drilling rig gives more accurate drilling, resulting in a more accurate overbreak.
(3) The productivity of the drilling rig is higher owing to the use of a smaller labour force.
(4) The rig needs very little physical labour to accomplish the work, resulting in greater worker productivity.
(5) With the rig, the drilling operation as a whole is far quieter with less mist, thereby making the drilling activity more pleasant and acceptable to workers.
(6) The drilling operation using the rig is less hazardous. The operator stands away from the machine boom while drilling. Hence, should a drill rod break during drilling, it is unlikely that he will be injured, which is not the case with hand-held drills. The drilling of long cover holes is far more accurate with the drilling rig. Should water be intersected, injury is less likely than is the case with hand-held drills.
(7) Cover drilling is far more accurate with the rig and is generally safer.

However, the drilling rig has the following disadvantages.

(a) It involves a high capital outlay.
(b) Engineering, as well as operating, personnel must be trained in its use and maintenance to ensure continued

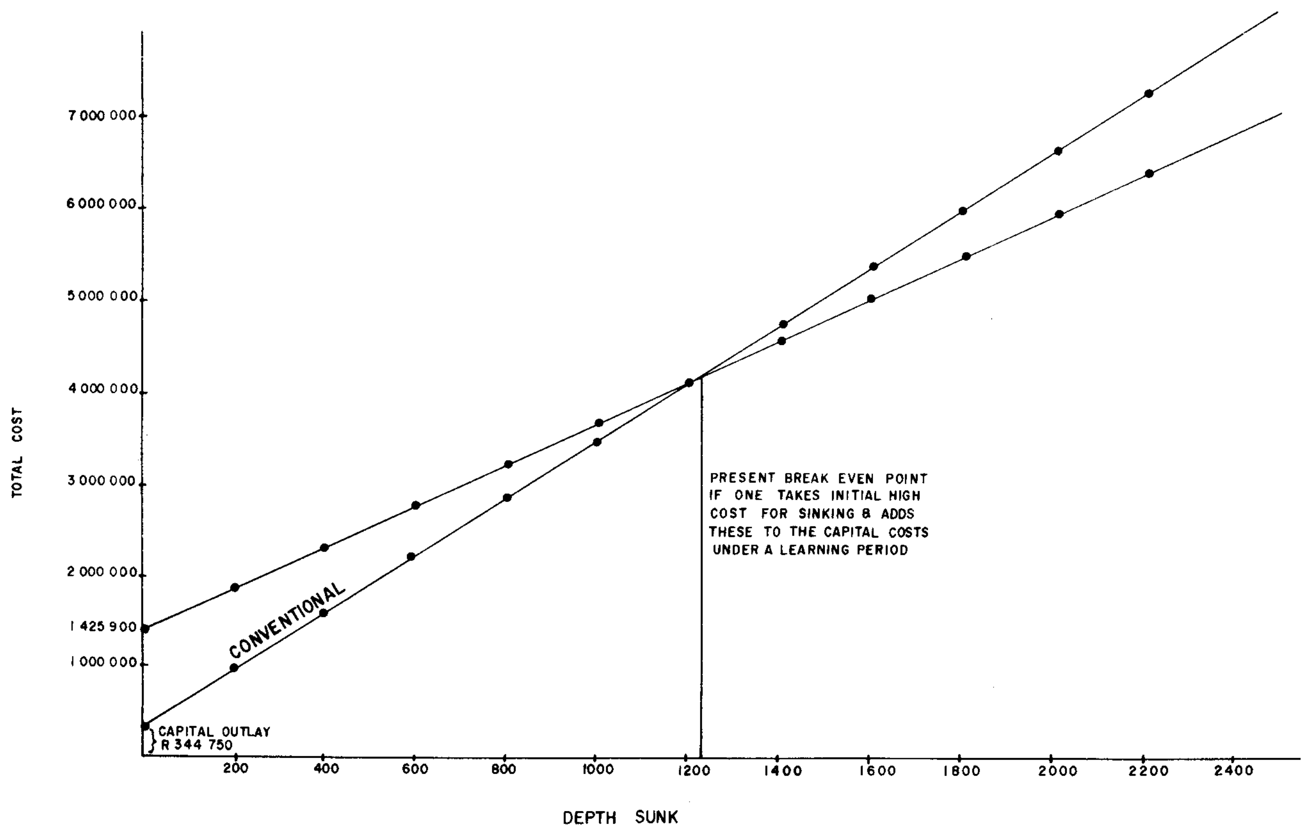

Fig. 9—The total costs of drilling with the rig and with hand-held drills

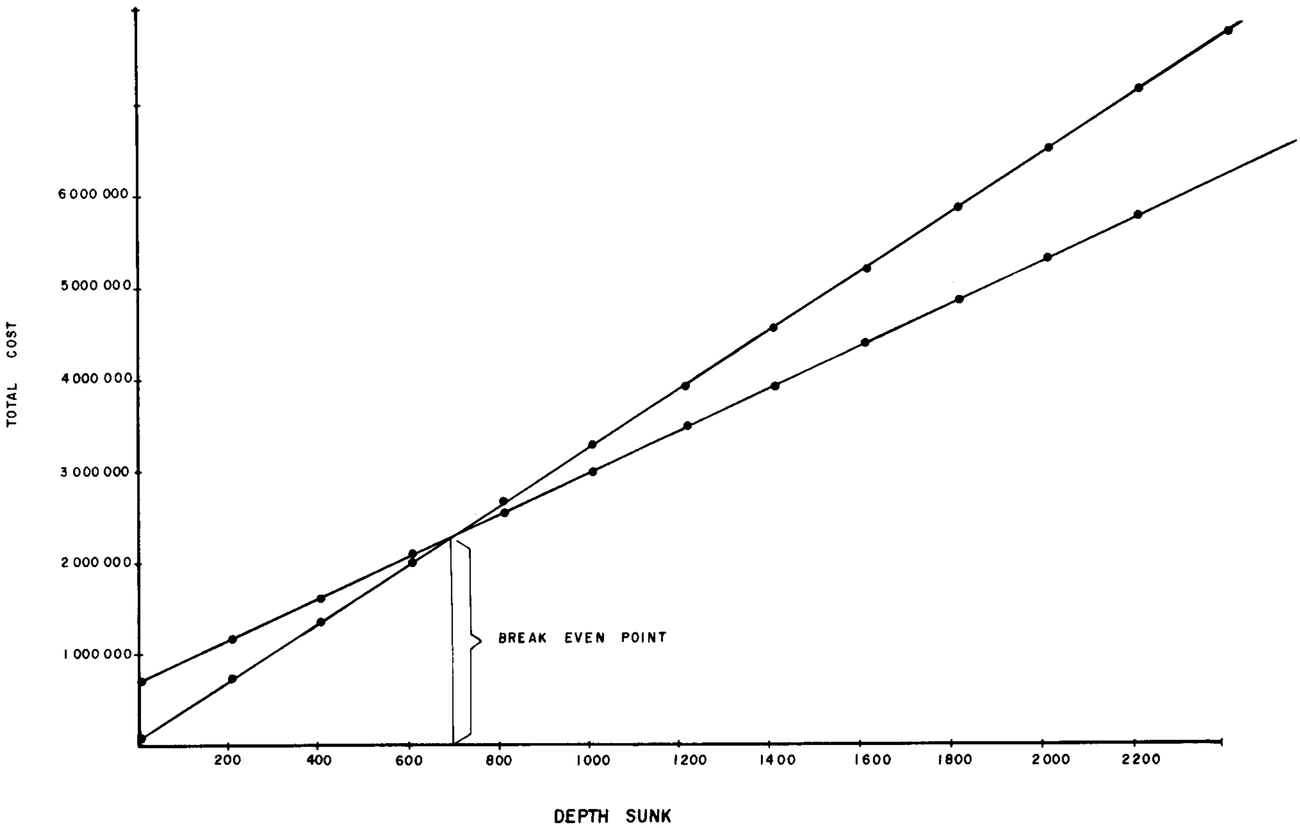

Fig. 10—The total costs of drilling with the rig and with hand-held drills when the rig is used at a second shaft

success.

(c) Any major failure of the machine, such as failure of the main hydraulic pump, results in a complete failure of the drilling activity.

(d) Stations cannot be cut with this drill rig. Hand-held machines must therefore be purchased for this purpose.

(e) Support holes cannot be drilled, and hand-held machines are therefore required for this purpose.

Despite the disadvantages, there is no doubt in my mind that a drilling rig for use in shaft-sinking operations will become the order of the day within the mining industry. The high cost of labour will make it even more viable as time passes. The use of drilling rigs in shaft sinking now makes it possible to describe the whole operation as 'fully mechanized'.

Addendum: Technical Specifications

7-boom rig with down-the-hole hammer

Height	7 200 mm
Diameter	2 100 mm
Overall mass	14 000 kg

Shaft-sinking boom:

Reach:	850 mm to 5 000 mm.
Feed:	Atlas Copco hydraulic feed type BMH 153 Maximum feed force at 100 bar hydraulic pressure: 7,9 kN. Maximum return force at 200 bar hydraulic pressure: 7,9 kN. Maximum hole depth: 4000 mm Maximum overall length: 5450 mm Feed dump 65° (for station brow drilling) Feed swing 10° (for cover drilling)
Rock drills:	Atlas Copco COP 932 Net weight, excluding cradle: 130 kg Length × width: 810 mm × 250 mm Stroke rate: 51 Hz Rotation speed: 0 to 300 r/min Maximum torque on drill: 120 Nm Air consumption at 6 bar: 50 l/s.

Atlas Copco Pneumatic Power Packs

Hydraulic pressure	200 bar
Hydraulic capacity	38 l/min
Number of power packs	3.