South Deep – The Challenges

By

M Bevan
Director Marketing [Retired]

Cementation Mining Skanska [Pty] Ltd

SYNOPSIS

This paper deals with the challenges encountered in sinking the deepest single rock hoisting lift shafts in the world and includes the following:

1. The Purpose of the South Deep Shafts

Over years of exploration the massive and tabular ore bodies in the area to the South West of Western Areas Gold Mine had been assessed as containing about 50 million ounces of gold – a world class ore-body.

Planning initially was for a surface and sub vertical shaft system to exploit this area but because of cost, a single lift shaft to an area which could be accessed ex Western Areas was planned to intersect the reef at 2 760 metres.

It was also planned to mine out the shaft pillar area long before the deep shafts would reach that position.

This is not the normal practice in South African Gold Mines. The stoped out shaft pillar was backfilled to minimise movement in the shaft sites.

The result of a competitive tender/adjudication process was that Cementation Mining – Skanska won and was awarded the R192 million contract to sink the Main and Ventilation Shafts on the 15th of June 1995.

On the 1st of April 1999 Western Areas and Placer Dome S.A. formed a Joint Venture, which now owns and operates the mine on which the South Deep Shafts are situated. This situation prevails today.

2. The Shafts, Broad Specifications

2.1 Main Shaft

This shaft was planned at 2 760 metres deep [now 3 023,15 metres] and a lined diameter of 9,0 metres and includes 10 stations. The Headgear is a 93,25 metre structure comprised of 6 100m³ of reinforced concrete equipped with 685 tons of steel. The headgear slide took 40 days and rose at 115mm per hour.

The Main Shaft is planned to be equipped with four compartments, two for rock hoisting and two for men/material transport. [Figure 1].

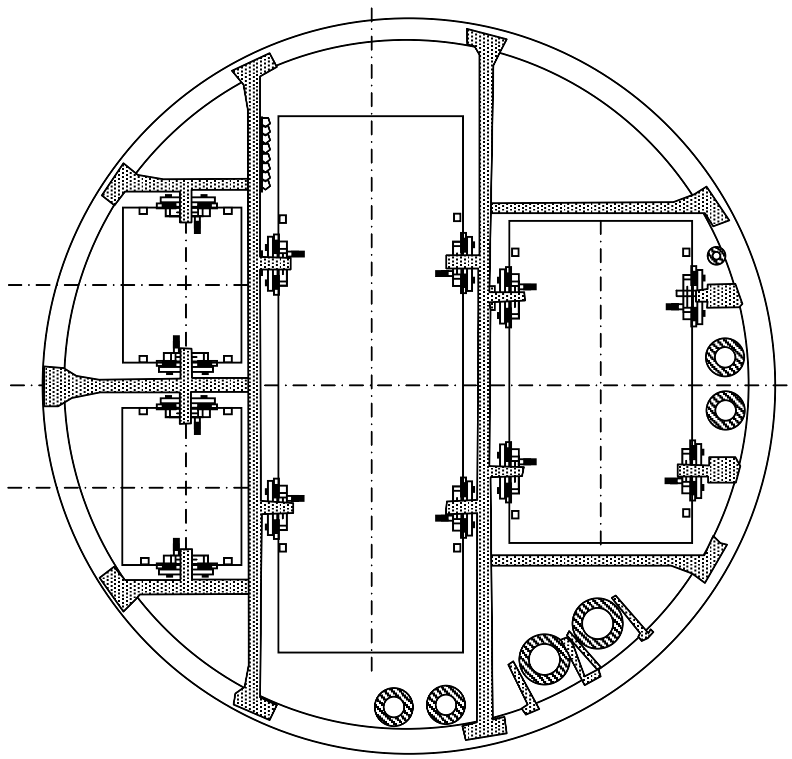


Figure 1: Main Shaft Permanent Configuration

2.2 Ventilation Shaft

This shaft was planned at 2 765 metres deep [now 2 759,5 metres] with a lined diameter of 9,0 metres and includes 7 stations.

The headgear is also of reinforced concrete construction and the shaft is designed for upcast and downcast sections separated by a brattice wall.

The downcast section of the shaft is to be equipped with two compartments for men/material hoisting only **[Figure 2].**

The equipment used for the sinking of the two shafts is shown **[Table 1].**

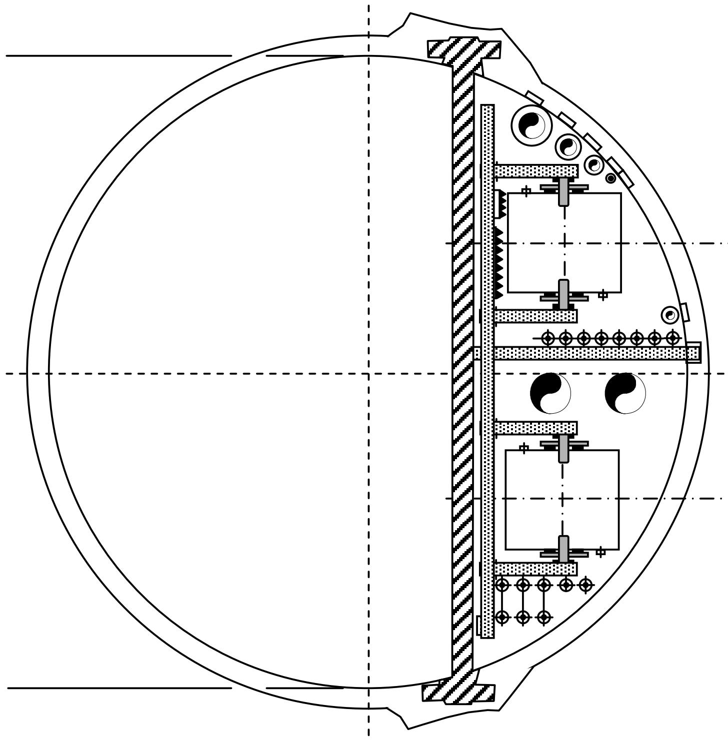


Figure 2: Ventilation Shaft Permanent Configuration

TABLE 1: Equipment Used for Sinking

Equipment Used for	Main Shaft	Vent Shaft
Shaft Drilling	7 Boom Jumbo	7 Boom Jumbo
Round Length	6,4m / 3,2m	3,2m
Rock Drills	Seco 140	Seco 140
No. of Holes	145	145
Kg of Explosive/Round	1,6 / 0,8 ton	0,8 ton
Kibble Payload	16 t	16t / 12t
Lashing Unit	30 cu. ft	20 cu. ft
Kibble Rope Diameter	47mm	43mm
Kibble Rope F.O.S.	3,54	3,67
Stage Rope Diameter	43mm	34mm
Stage Rope Safety Factor	3,86	3,70
No. of Falls/Rope	4	4
Stage Mass	130t	110t
Shaft Bottom Original	-2 760m	-2 765m
Shaft Bottom Revised	-3 023m	-2 759,5m
Concrete Lining	20MPa	20MPa

3. The Challenges

3.1 Safety

Safety is the first Agenda item at **all** meetings. "Cementation Mining – Skanska believes it is the inherent right of every employee to work in a safe and healthy environment".

In South Africa poor safety can result in severe sanction against individuals and companies and so, together with our beliefs, we put in place at South Deeps a comprehensive Safety and Training System.

The system caters for the following:

- Compliance with all safety legislation
- Establishment of a safety committee
- Compliance to the NOSA safety system and the ISO 9002 accreditation
- Education and training of our employees.

The safety and training structure on the South Deep Project consists of a full time Safety Officer, Training Officer, 2 full time Safety Team Leaders and 15 Safety representatives per shaft.

The main elements in the Safety/Training programme are that before any work is started a risk assessment is done. Following the risk assessment a work procedure is developed, written and approved by the Site Management and the client and finally the employees are trained in that work procedure.

A total of 376 work procedures split up as follows:

Induction	28 procedures
General safety	44 procedures
Sinking operations	55 procedures
Shaft lining and services	34 procedures
Rock support	17 procedures
Lateral Development	85 procedures
Survey/Geology	15 procedures
Maintenance	71 procedures
Administration	15 procedures
Equipping	12 procedures
	376 procedures

On South Deep we are on the 7^{th} cycle of re-training in work procedures and have conducted over 4 000 training exercises.

We believe that on the job training and certification **produces ownership** for our employees whose input is used in drawing up the procedures and systems in the first instance.

The achievements on the Ventilation Shaft have been exceptional namely:

- NOSA Terry Trophy – Best Continuous Safety Performances
- NOSA Best Contractor Trophy – In the Cosmos Region
- NOSA 5 Star Grading : 6 times
- Cementation Shield : 2 times – Best Overall Safety Statistics
- Group Chairman's Shield : 3 times – Most Improved Contract
- Client Safety Performer : 9 times
- Club 100 Merits – 4 times
- Club 200 Merits – 2 Times

At time of writing the deepest shaft in the world sunk fatality free accumulating 655 236 shifts fatality free.

The Main Shaft's record is not as good and since the start of sinking we have had five fatal accidents. One was as a result of the failure of the lashing unit rope, one a fall from the stage and three fall of ground accidents.

The shaft has however achieved the following:

- NOSA 5 Star grading : 6 times
- Group Chairman's Shield : once
- Cementation Shield : once
- Client safety performer : 14 times
- Club 100 Merits – 4 times.

The shaft is currently on 102 109 fatality free shifts.

The safety achievements on the South Deep Project have been as a result of our workforce, our management, the client's management and our combined **zero tolerance** approach to the safety aspect.

3.2 Flooding

On the 1st of May 1996 we blasted into an aquifer at the contact between the bottom of the Pretoria Shales, the top of the Malmani Dolomites and the intersection of the Broken Arrow fault making an estimated 10 000 litres per hour at a depth of 447 metres. **[Figure 3].** After 12 hours of support and other work in the shaft bottom, during which the inflow increased, bailing by kibble could no longer contain the inflow of water now estimated at 80 000 litres per hour and later fixed at 165 000 litres per hour. The water level was rising at an alarming 2 metres per hour, which demanded a tactical retreat on the stage up the shaft.

Whilst suitable submersible pumps were sought services were stripped up the shaft behind the rising water for 2½ days. On the 6th of May at 14H00 pumping using two Pleuger pumps started after the water had risen to 309 metres [138 metres above the bottom]. The pumps delivered 250 000 litres per hour to surface through the existing service pipes in the shaft.

By the 11th of May the water level had been lowered to 439 metre level and it had been decided by the crisis committee chaired by JCI's chief consulting mining engineer, John Brownrigg, to attempt to diamond drill holes from the stage to intersect the aquifer. The plan was to intersect the source and attempt to seal it by way of grout injections. This attempt took 5 days after which it was abandoned due to lack of progress/success.

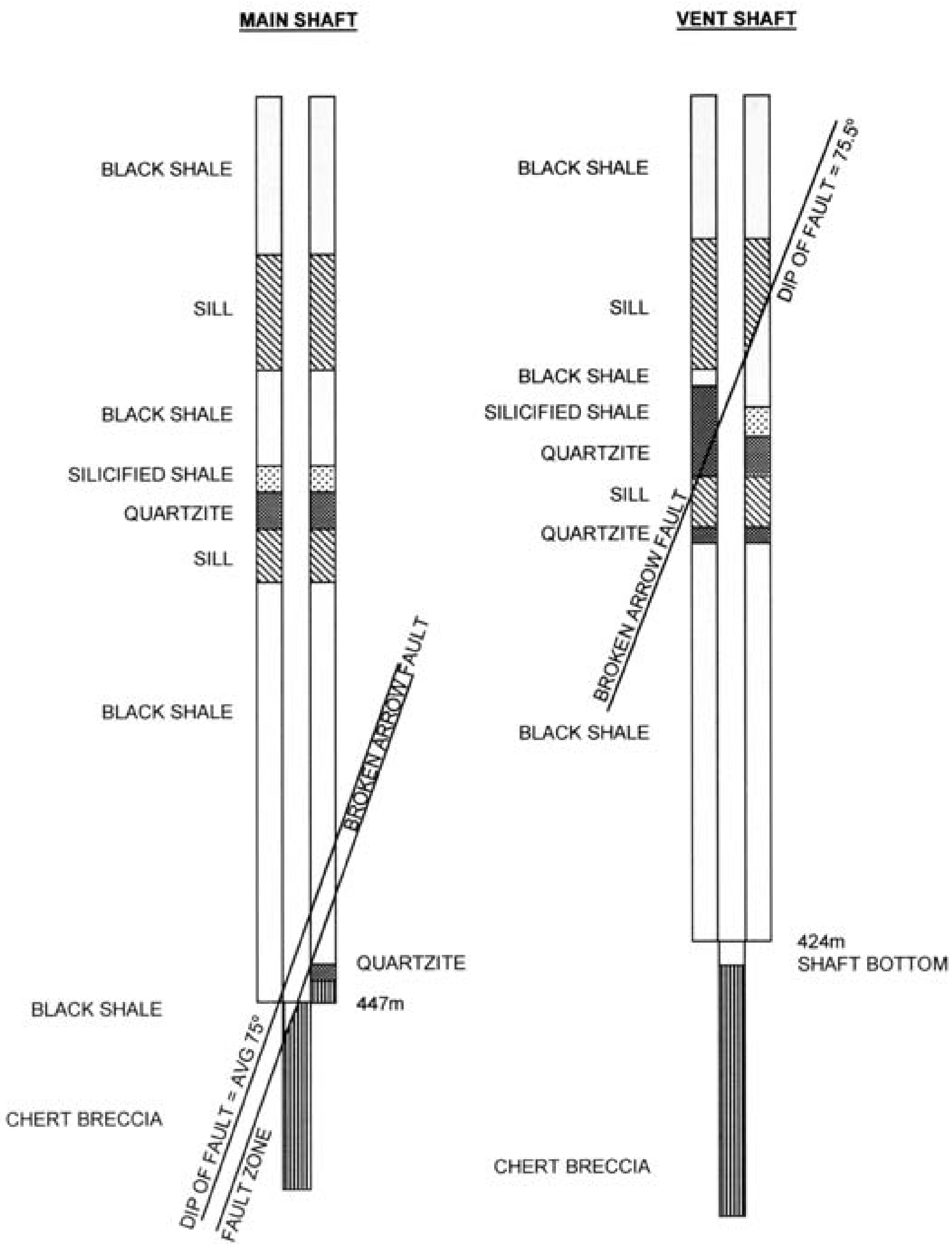


Figure 3: Broken Arrow Fault Intersection

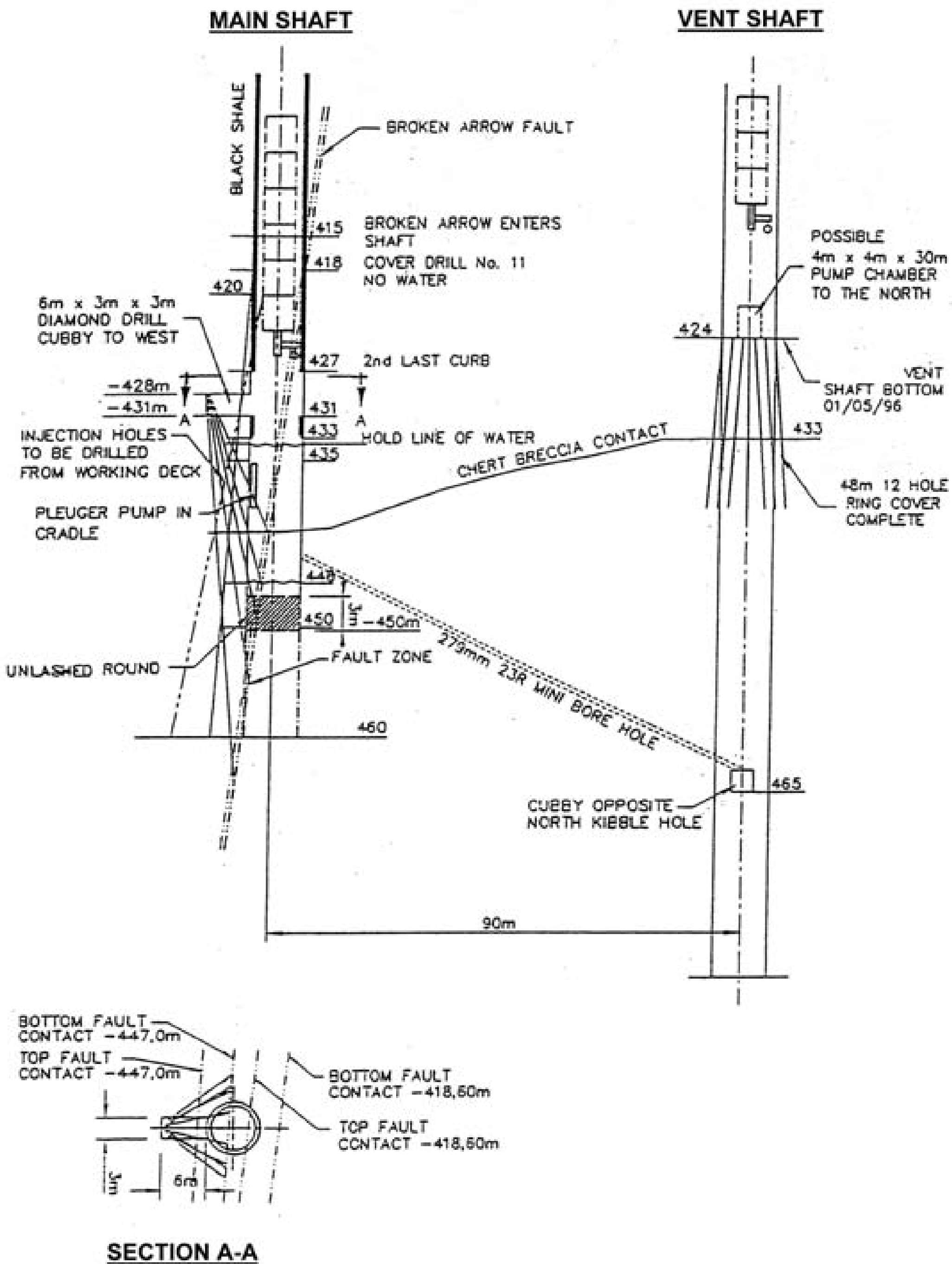


Figure 4: Flood Recovery Alternatives

A further 5 alternatives were considered **[Figure 4]** namely:

- A new cubby blasted in the shaft sidewall to afford a better platform for diamond drilling
- A drain hole from the adjacent Ventilation Shaft

- Flooding to water table and casting of an underwater plug [Done successfully at Western Deep Levels South in 1982/83]. This mine is situated in the same dolomitic measures as the South Deep Shafts. This method was discarded in favour of casting a plug in the dry man access facilitating certainty, quality and speed of construction.
- Casting of a plug on the curb, which was already cast on the shaft wall.
- Finally the preferred method which was a plug above a French drain constructed on the muck pile in the shaft bottom **[Figure 5].**

In the Republic of South Africa plugs must conform to a Chamber of Mines Code of Practice. The design of the plug was based on maximum pressure 4,5 MPa [full static head], a plug/sidewall interface shear resistance of 830kPa, a designed concrete strength of 30 MPa at 28 days and a pouring rate of 10 – 20m³ per hour.

The plug length was determined at 15 metres and 134 tightening pipes were installed.

On the 27th of May 1996 a meeting was held with the Government Mining Engineer and the plan gained his blessing provided that the requirements of the plug construction Code of Practice catered for procedures, which were to be drawn up.

From the 18th of May to the 27th of May 1996 the French drain was constructed and on the 27th the drain was covered with P.V.C. geo fabric in preparation for the concrete placement.
Casting began at 10H00 on the 28th of May and was completed at 15H00 on the 31st of May. The total 1 132m³ of concrete was poured at an average rate of 14,7m³ per hour.

The plug was allowed to cure for 5 days before tightening commenced.

On the 12th of June 1996 the two 900mm diameter draught pipes were capped with flanges bringing the inflow under control.

The pressure on the plug rose to a maximum of 3,2 MPa.

On the 13th of June 1996 reverse flow water was introduced through the draught pipes at the rate of ± 60 000 l/h. **[Figure 6].** A cement water grout was intruded into the reverse flow stream starting at 100 – 150kg of cement per 300 litre batch of water and gradually thickening through 450kg to finally 600kg per batch.

On the 23rd of July 1996 after accepting some 7 340 000kg of cement and 11 megalitres of reverse flow water the offending water source finally choked off.

It was now time to check if in fact the source had been sealed. Some 3 754 metres of diamond and percussion drilling was done in about 100 holes. A further 180 000kg of solids were injected into these holes.

On the 7th of September 1996 some 46 days after the reverse flow sealing had been completed it was decided that the water source had been effectively sealed.

Removal of the concrete plug was now started by drill and blast methods. Core drilling of the plug proved the quality to be 33 MPa concrete.

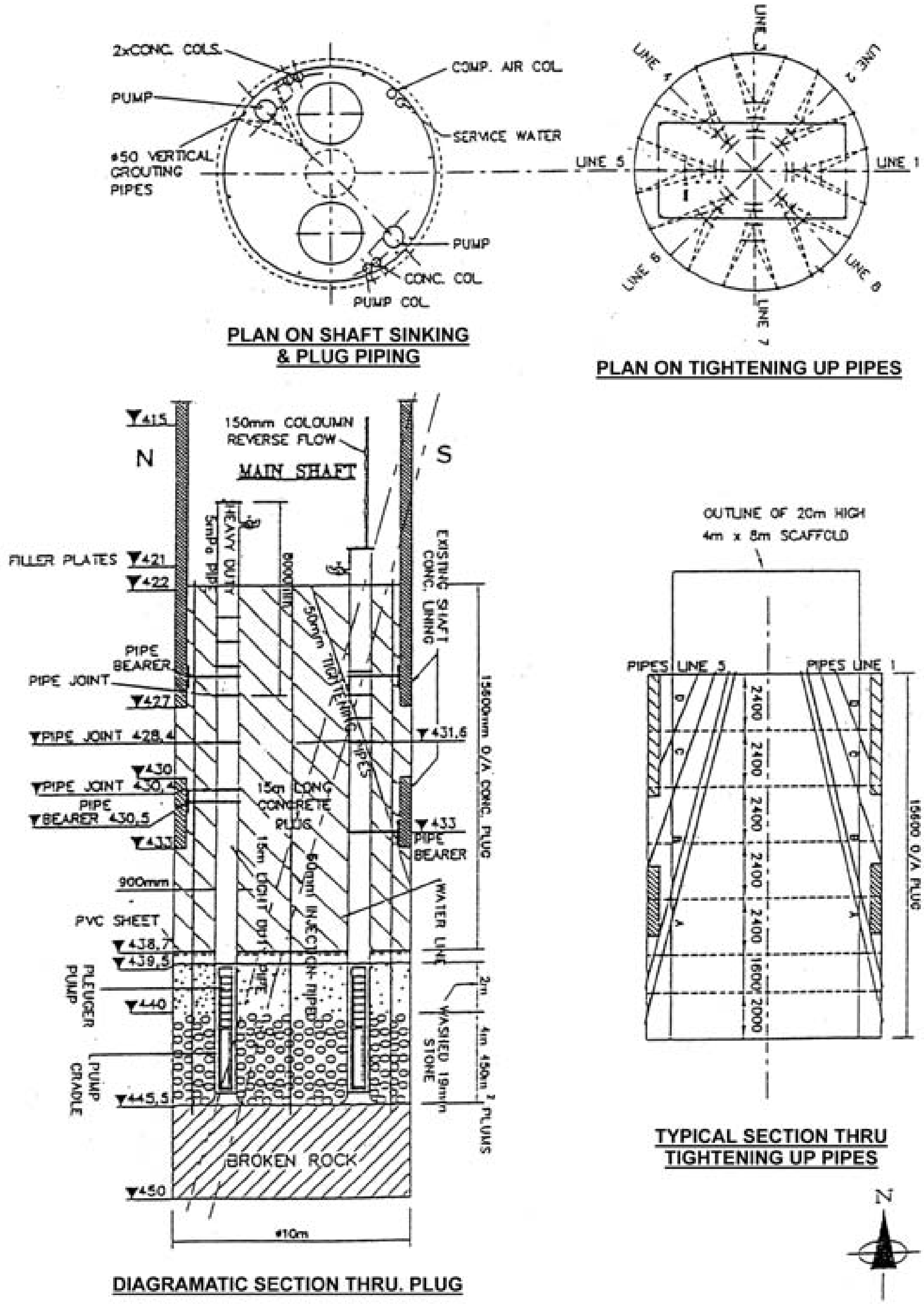


Figure 5: Shaft Plug

The plug was completely removed and the shaft cleaned to its bottom on the 8th of October 1996.

Sinking now re-started including cover rounds as shown. **[Figure 7].**

The total delay to the sinking had been 5 months, 3½ months reverse flow and 1½ months construction and removal of the plug.

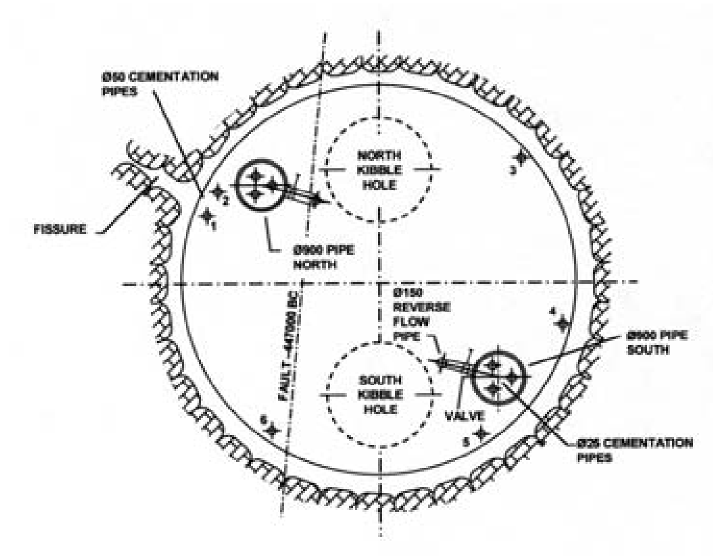


Figure 6: Plan view of reverse flow process pipes

Floodings of any sort are to be avoided at all cost, but the success here was due to the close cooperation between all the stake holders client / contractor / consultants / Department of Minerals & Energy and suppliers.

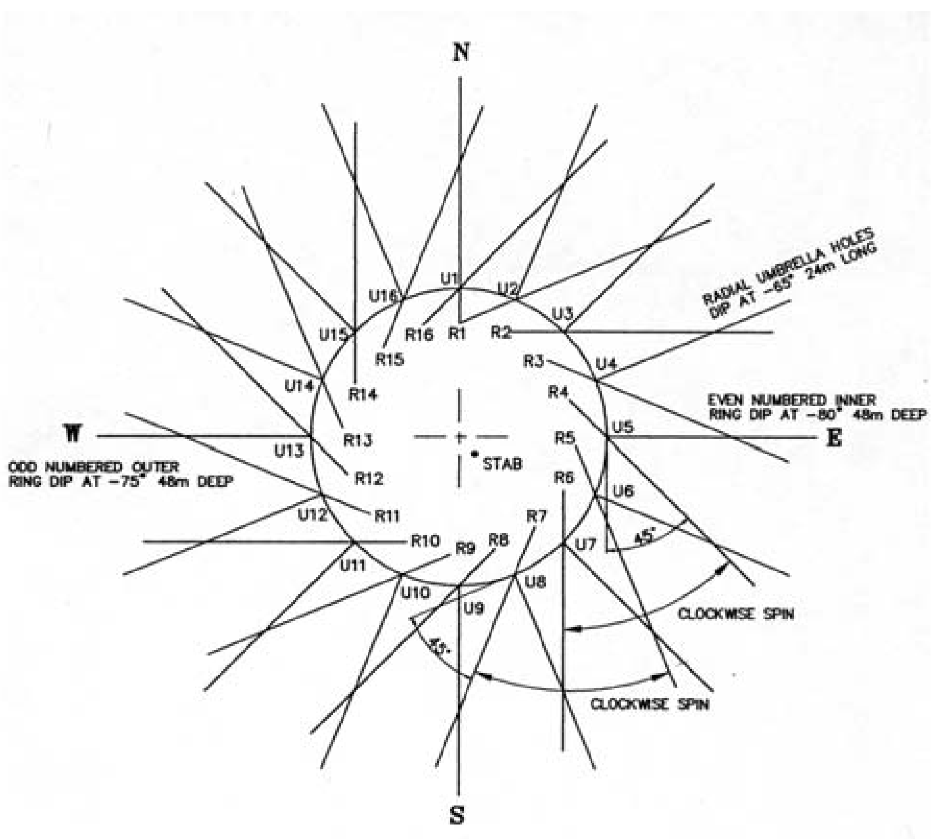


Figure 7: Typical Cover Drill Rounds used in Dolomites

3.3 Sinking Through the Reef Horizon

In order to overcome ore lock up and later stressful shaft pillar extraction and subsequent shaft damage, the client mined out the pillar from the established mine. The reef dips at around 20º at the Main Shaft and was stoped out at a width of ± 1,5 metres. The Ventilation Shaft is sited in a normal fault loss area; this plane was likewise stoped out. While the stoping out of the pillar took place the mined out area was back-filled with mine tailings, aggregate and 4% cement backfill.

The shaft pillar area, which was mined out is of the order of 200 000m^2, which is all backfilled.

This was done to minimize rock movement. Residual closure is accommodated by suspending the shaft steelwork in a compressible tower spanning the destressed zone.

As the shafts approached the mined out area at 2 535 metres, probe/pilot holes were drilled to intersect the mined and filled area. The area elevation was identified and mining into and through it presented no problem. The hanging wall and footwall of the stope was drilled and blasted whilst the fill was moiled out using paving breakers. The fill area needed to be mined out for 2 metres all around the shaft and it was originally planned to concrete this area. With the stiffness of the fill it was decided not to do this but mat/strap the area and place

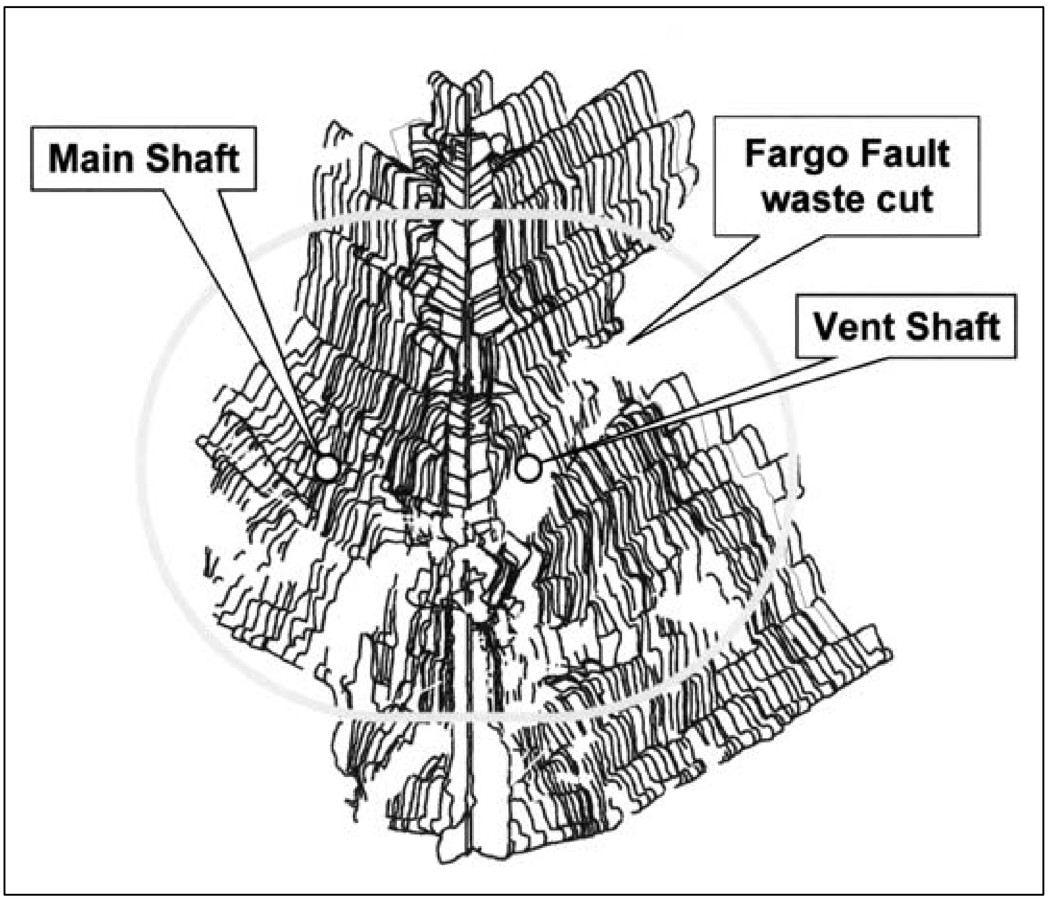


Figure 8: Mined Out Shaft Pillar

150mm of fibre reinforced shotcrete over the mat/strapping.

The shaft pillar mined out area and shafts are shown **[Figure 8].**

The hanging wall and footwall brows and the whole area was well supported by the use of normal grouted rockbolts and 6 metre long rope anchors which are shown **[Figures 9 and 10].**

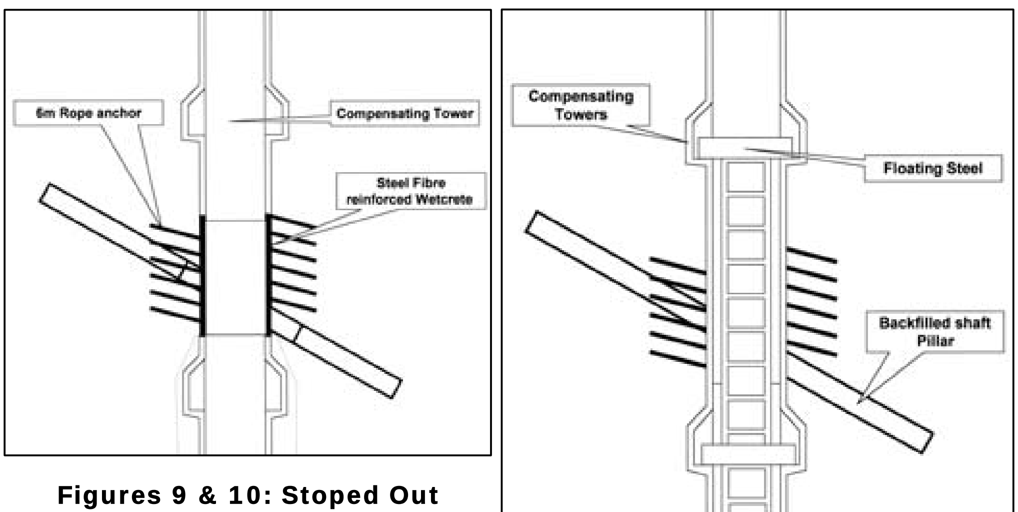
Whilst going through this area some disruption to the normal shaft sinking cycles was suffered, but it only slowed things down and was not technically difficult.

The total distance over which these disruptions were encountered was 25 metres and was completed in 18 days.

The stoped out area has not negatively impacted on our sinking activities since we moved below and away from it.

It is our opinion it will not impact in the long term either.

Vertical closure deformation that was designed for in the Main Shaft is 3,15cm and the Ventilation Shaft 2,94cm.



Figures 9 & 10: Stoped Out Area Support

3.4 Stage Masses – Ropes and the Stage Rope Move

Ten years ago the deepest single lift shaft in South Africa was Hartebeestfontein 6 South Shaft at 2 433 metres. Planning to sink to 2 700 metres plus demanded consideration of stage masses and rope types.

The general winding parameters are set out in **Table 2** and the site plan for the winders in **[Figure 11].**

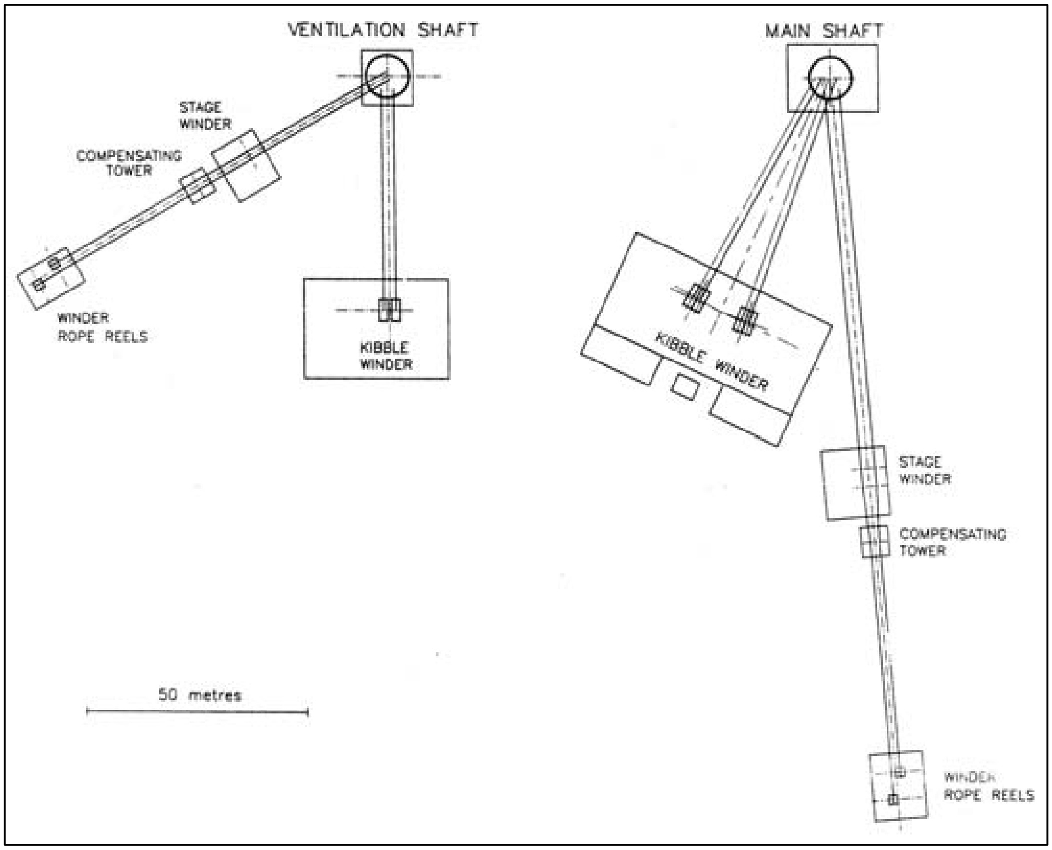


Figure 11: Winder Site Plan

Stage winders licensed raise, lower and hold designed stage mass. **See Table 2.** 153 tons for the Main Shaft and 114 tons for the Ventilation Shaft [both shafts 9m diameter]. Maintaining these weights is paramount if one is to remain within the factors of safety.

The Ventilation Shaft stage required extensive use of aluminium in order to meet the 114 ton mass restriction.

Stage mass control hinges around discipline. As an example South Deep stages had collected over time as much as 10 tons of concrete spillage which must be controlled. This aluminium stage caused major maintenance problems. This material and the construction would not be used by us again.

Stage mass monitoring at South Deeps is done by the use of load cells in the headgear on the rope dead ends, which give continuous mass which is read on an instrument in the Banksman's cabin. Action can be taken immediately so as not to compromise the factor of safety.

In South Africa winding rope factors of safety are the subject of regulation. The required static factor of safety is 4,5. This is calculated by dividing the rope tensile strength by the total suspended weight.

TABLE 2: General Winding Parameters

No.	Criterion	Main Shaft	Ventilation Shaft
1.	Excavated diameter	9,6m	9.6m
2.	Lined diameter	9,0m	9,0m
3.	Depth on 22/6/00	2 779m	2 571m
4.	Ultimate depth	2 995m	2 780m
5.	Sinking duration to date	56 months	58 months
6.	Ventilation	Force down/force exhaust	Force down/force exhaust
7.	Shaft water ingress	Wet shaft	Wet shaft
8.	Water quality pH	6 – 10	6 – 10
9.	Water chloride content	Low	Low
10.	Rock hoisted to date	638 000 tons	580 000 tons
11.	Estimated kibble winder reversals to date	62 000	56 000
12.	Kibble rope dia.	47mm	45mm
13.	Kibble winder drum dia.	5,1m	4,8m
14.	Kibble head sheave dia.	5,5m	4,8m
15.	No. of stage kibble holes	2	2
16.	Kibble winding speed	15 m/s	15 m/s
17.	Kibble winder drive	8 400 kW BMR on single rope	3 400 kW double drum
18.	Stage suspension	2 x 4 falls	2 x 4 falls
19.	Stage winder drive	650kW Lebus two drum friction	187 kW single drum chimes friction
20.	Licensed stage mass	153 tons	114 tons

The South Deep shafts have through exemption and the application of “deep sinking codes of practice” been permitted to operate at factors of safety of 3,8 and 4,0 for the Main and Ventilation Shafts respectively. **Table 3** is a check list for compliance with the code.

Table 4 is a list of winding procedures for sinking.

The stage ropes have performed well during the execution of the project. The client increased the depth of the Main Shaft by about 300 metres and the stage ropes were too short. This problem was elegantly solved see:- **[Figures 12, 13, 14 and 15].** The operation took 36 hours.

The kibble ropes in both the Main and Ventilation Shafts have however presented many problems. Starter [1 000 m] and intermediate [1 800m] ropes on both shafts performed well and were replaced when they became too short.

TABLE 3: Deep Sinking Code of Practice Check List

Item	Requirement	Action
1.	Maximum kibble rope load during [normal] controlled braking shall not exceed 40 percent of initial rope breaking strength.	Client has installed fully closed loop braking system. Continuous rope load monitoring in place.
2.	Continuous stage rope load measurement on dead ends within 1 percent	Real time measurements being made continuously and recorded.
3.	Kibble front end rope splices no longer accepted. Ropes to have socketed connections.	Implemented
4.	Rope condition assessment to SABS 0293:1996	Current practice
5.	Tensioning of kibble rope back-ends 6 monthly and pulled independent of condition	In place. Back-ends 3 monthly
6.	3 monthly stage rope load cell calibration	Implemented
7.	Check on theoretical dynamic loads [load range] in kibble ropes to be carried out	Calculations done. Accelerations and decelerations controlled to keep within limits.
8.	Minimum of 3 monthly kibble rope assessments	Monthly magnetic rope testing

TABLE 4: Site Specific Work Winding Procedures for Sinking

Winders		
1.	SD-WP317	Clutching on kibble winder
2.	SD-WP802	Daily electrical inspection – Main Shaft kibble winder
3.	SD-WP804	Daily mechanical inspection of kibble winder
4.	SD-WP805	Weekly mechanical inspection of kibble winder
5.	SD-WP806	Weekly electrical inspection of kibble winder
6.	SD-WP824	Moving Vent Shaft stage should the rope slip through the chimes
7.	SD-WP829	Procedure for maintaining Hooke's joint on Main Shaft kibble winder
8.	SD-WP830	Procedure for winder lock-out on hoist exam
9.	SD-WP831	Lapping of brakes

Ropes		
1.	SD- WP220	Procedure for changing kibble ropes

2.	SD- WP331	Main Shaft stage rope change
3.	SD- WP832	Removing and replacing of stage ropes
4.	SD-WP865	Lowering of stage rope dead ends

Slinging		
1.	SD-WP222	Procedure for slinging material up to 10 ton to station
2.	SD-WP302	Slinging jumbo drill rig in shaft and handling on surface
3.	SD-WP322	Work procedure to sling 630 loader
4.	SD-WP326	Slinging in shaft
5.	SD-WP328	Working procedure to sling LHD

General		
1.	SD-WP105	Banksmen / WED back out procedure
2.	SD-WP309	Hooking on and off of kibbles on the shaft bank doors
3.	SD-WP314	Tipping of kibbles
4.	SD-WP315	Bell ringers
5.	SD-WP319	Work procedure for winding engine driver
6.	SD-WP807	Weekly headgear examination
7.	SD-WP816	Procedure for checking loadcell readings
8.	SD-WP840	Crosshead separation fault finding procedure

Two generic types of failures have been experienced on both shafts with the +3 000 metre ropes. These are accelerated wear at the approximate midpoint of the ropes resulting in four strand failures without warning in four different ropes.

Another problem is age induced loss of approximately 4% of tensile strength. Magnetic rope testing did not provide any warning of impending wire failures.

The second cause of concern was the appearance of waviness at the front ends due to slack/tight strands.

Front-ends which were normally cut and tested on a six monthly basis are now done quarterly. Back-ends are not normally cut on medium depth shafts. Because of the rope failures a two monthly precautionary back-end programme has been implemented although strand damage was not at crossover points.

In learning from the failure investigations accelerated strain ageing footprints should be requested from the supplier of the rope. This would be used as a guide. It is also a good thing to have for all winding rope purchases.

The loose/tight strands and waviness in the ropes we experienced has resulted in more front end cuts than we planned with this phenomenon occurring from the splice/socket to 100 metres and around the tangent point when the kibble is in the tipping position. This did not happen with the shorter starter ropes.

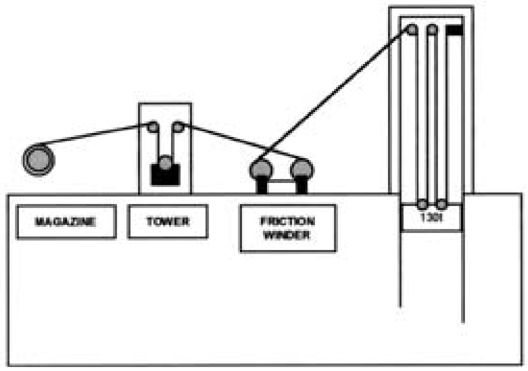


Figure 12: Raise Stage to Sub-Bank level

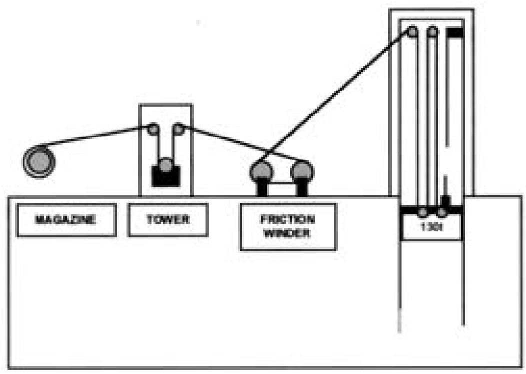


Figure 13: Install special steel frame, clamp & cut ropes.

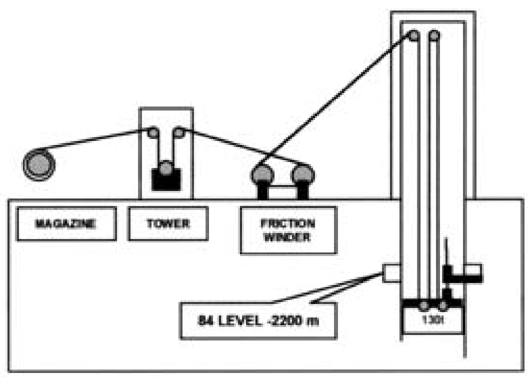


Figure 14: Clamp loose end of rope onto cantilever on 84 level.

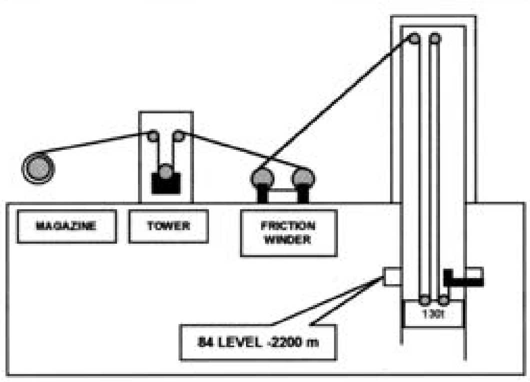


Figure 15: Remove special steel frame, resume normal operation

At South Deeps we have been exposed to rope problems as never before and we learnt and are still learning. Rope management is a three way thing, supplier, client and us the contractor.

On completion of the shafts it is our intention to provide a final assessment and report on the rope saga. In the meantime we are continuing with our precautionary programme.

3.5 Shotcrete Lining the Shaft Wall

Because of strict quality control we decided not to drop the material through the slick lines.
In order to mix and handle the wet fibre reinforced shotcrete we constructed a facility on surface including a belt, which discharged the wet mix into a purpose converted kibble holding 2,5m³ of material. This kibble was lowered to the shaft bottom with the mix ready for spraying.

The 2,5m³ material in the shaft bottom was discharged into a hopper from where it was pumped by a Rambo pump to the discharge nozzle where the compressed air [25mm] and Meyco SA160 accelerator was introduced. A basket was hung from the cactus cross head from which the nozzle operator sprayed the material onto the shaft wall.

During spraying shotcrete thickness is controlled with probes of 50mm, 75mm, 100mm depending on specified thickness.

TABLE 5: Fibre Reinforced Shotcrete Mix

	Mix No. 12 19.06.2000	**1m³ [kg]**
Pre Bagged Supply	CEM 1 52,5	475
	Superpoz	75
	Silica Fume	38
	6,7mm stone	262
	Crusher sand	1080
	Stella Sand	160
	Fibrin	0,91
	Harex	40
Additives Put Into Mix At The Mixer	Delvocrete	4,0
	TCC 735	5,0
	Glenium 27 CH	5,0
At Spray Nozzle	Meyco SA 160	43
At Mixer	Water [Total]	200 litres

For strength and other quality control tests we sprayed 2 test panels for every 3 metres of shaft we sank. These panels were taken out of the shaft, cured and sent to an independent quality controller. Cubes of the material were also made at the plant on the shaft head for quality testing.
The mix design is as set-out in **Table 5.**

A total of 380 metres in each of the shafts in the destressed zone was lined by this method.

It was our first experience of ***wet*** fibre reinforced shotcrete and it proved to be superior to ***dry***. The dust is reduced and it is safer.

The shotcrete was planned at a strength of 50MPa and an energy absorption of 800kJ. We achieved strengths of as high as 80MPa with the odd one below 50MPa. Absorption results reached as high as 1000kJ.

3.6 Poor Ground Support Methods through Shales

In poor ground conditions we have made extensive use of straps which are 6 metres in length and 300mm wide as well as mats which are 1,8 metres wide and 3 metres in length hinged in the middle making two sections of 1,8 metre by 1,5 metres in size. The straps and mats are made of 10mm rods and 5mm wire, which binds them together. The straps and mats are flexible and can be pushed into hollows in the rock wall.

In poor ground conditions attributable mainly to shale intersections/inclusions we use combinations of mats and straps to take support into the bottom instead of bringing the shaft lining down into the bottom which would waste a lot of time. The procedure is that after a blast of 3 metres we would lash out half of the rock and then cover 1,5 metres of shaft wall all around the circumference with the mats fixing them to the wall by using split set bolts and 200mm by 200mm flat plate washers. At this time the 3 metre long mat is hinged upward and tied temporarily with wire. The remainder of the round is then lashed out, the mats hinged down and again pinned using split sets. The whole wall of the shaft is now covered by the mats from bottom to the concrete lining which follows some 20 metres above.

This extends the sinking cycle by about 3 hours for every 3 metres, but we have a safe shaft with no exposed bad ground.

We have sunk and supported some 300 metres in each of the two shafts by this method.

There is however one slight drawback in using this method and that is the mats get damaged by the blast and about an hour is needed after each round of 3 metres to bleed and repair the mats.

We are from time to time requested to install 6 metre to 10 metre rope anchors during sinking at the discretion of the rock engineer. To do this we use a pneumatic drifter and cradle mounted on a pneumatic crawler for the work.

3.7 6 Metre Rounds and Half Rounds

In shaft sinking the "fewer the movements the shorter the cycle" and "when you are not lashing you are not sinking" made the application of long rounds a natural to improve on both of these.

Sinking comprises the following interruptions to lashing:

- Re-entry
- Stage moves
- Lashing start ups
- Blow overs
- Drilling and charging
- Blasting

All these above are delays in lashing, which we say is the only time you are sinking, so the fewer of these the better.

A second factor to be considered is the concrete lift length. The nearer the round length is to the concrete lift the better so 6 metre concrete lift 6 metre round is ideal [Pipes are tailored to match the lift length].

In the days of hand held drilling, shaft rounds of 2 metre effective length would have been called in 8 hours so 6 metres in 24 hours was possible.

When mechanised drilling of sinking rounds was developed the bottom drilling crews were reduced from say 50 men at one time to 17 men. This was safer and longer rounds could be jumbo/rig drilled mechanically.

So the longer the round the more the advantages to the project and whilst advances of 6 metres were possible in 24 hours "hand held" this was the limit, but with longer 3 metre/6 metre rounds the scope for improvement opened up.

In shaft sinking about 70% of the cost is time dependent so any reduction in time results in a dramatic improvement in profitability. A reduction in time for the client has a huge impact on his return on investment if he is able to earn from his new project earlier. The theoretical cycle times for the longer rounds appears in **[Table 6].**

Having decided hand held drilling was not the way forward and mechanised drilling was, the development of the shaft drill rig became a priority.

The rig designed and currently in use in South African shafts is one, which is brought from surface for the drilling of each round. It is fitted with 4 to 7 pneumatically powered drills. The rig comprises a central tower around which the drills are evenly spaced. A down the hole [D.T.H.] hammer can be included in the tower for drilling a cut stab hole of up to 250mm diameter. This provides the free breaking face for the round. Pneumatics also power a hydraulic pack which provides radial boom movement, thrust, radial and tangential rotation for the drills, slewing is by hand. A 7-boom drill rig for 3 metre blast holes weighs in the region of 16 tons. The rig designed to drill 6 metre blast holes in the Main Shaft at South Deep is 10 metres in height and weighs about 22 tons.

A 7 boom x 3 metre rig costs in the region of R3 million today. Formerly the investment in a rig, which could deliver 6 metres daily advance in one or two rounds was not commercially viable when similar advances were attainable by hand. However in 1990 the explosives supplier in South Africa stopped manufacture of the old parallel wired harnesses and changed to magnetic induction systems for shaft sinking and the resulting increase in round initiation cost meant that the investment in a drill rig could be recovered in 1 000 metres of sinking.

TABLE 6: Theoretical Cycle Times

	ROUND LENGTH	
ACTIVITY	**6m**	**3m**
Re-Enter	0,5	0,5
Bar & Make Safe	2,0	2,0
Lash 96 kibbles or 48 kibbles	9,0	5,0
Support	1,0	-
Blow Over	2,0	1,0
Drill	4,5	2,0
Charge Up	2,5	1,0
Clear & Blast	0,5	0,5
	22,0	**12,0**

Having invested in shaft drilling rigs we now had to make them work. In a very short time 3 metre rounds became standard practice but now what about longer? This was when we purchased the rig that could drill 6 metre blast holes for the Main Shaft at South Deep.

In Canada long rounds were a standard. The execution though is different. They use Crydeman clamshells for cleaning, we use a cactus unit. They use hydraulic drilling units mounted in the stage, we use our rigs slinging them up and down for each round. They use a D.T.H. which is brought to the bottom to drill the stab hole and sent out, ours is mounted in the rig central column.

During the sinking of the Main Shaft at South Deep many factors which prevented us from conclusively proving the long round technique were encountered.

We actually blasted 34 rounds in excess of 3 metres in length:

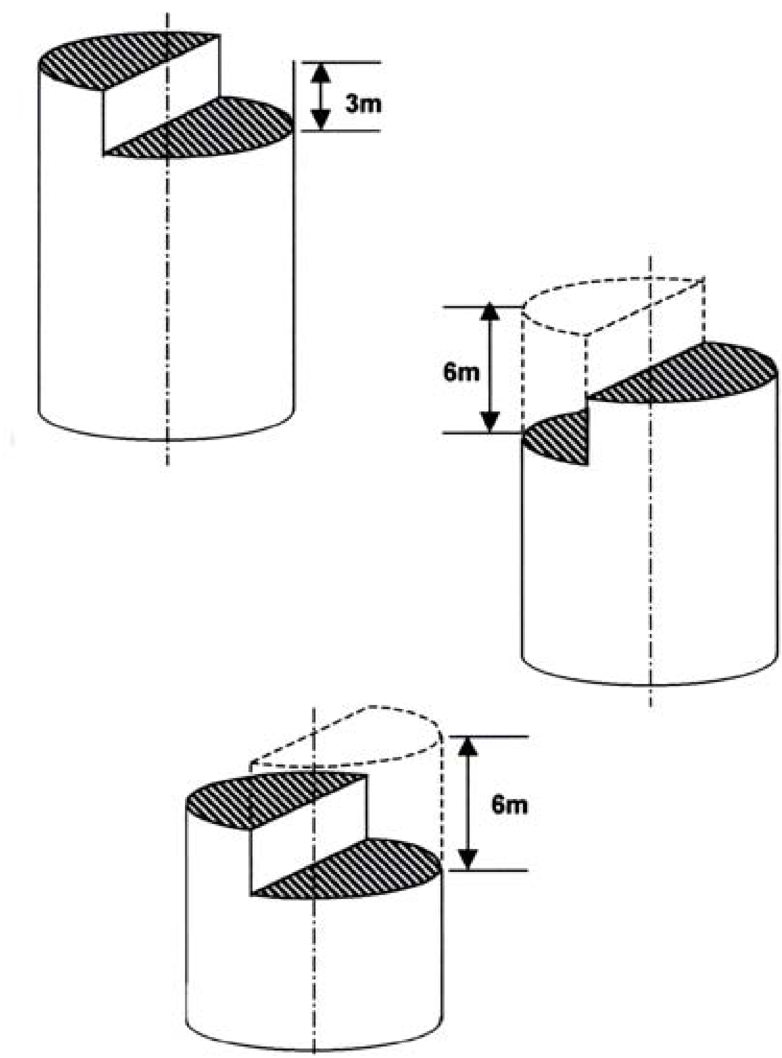
- 19 rounds 6 metres
- 3 rounds 4,5 metres
- 12 rounds 4,0 metres

In practice our site staff preferred the 3 metre rounds and these were used extensively during our sinking of the Main and Ventilation Shafts.

We have however proved that 6 metre rounds can be broken in all the rock types encountered on South Deep.

In the quest for improvement in shaft sinking drilling and blasting we also made an attempt at "half rounds" similar to shaft bottom benching which is widely practised by sinkers elsewhere.

The technique we tested in our experiment is that half the shaft bottom face led the other half by 3 metres. This is best explained pictorially. **[Figures 16, 17 & 18].**



Figures 16, 17 & 18: Half Rounds

We conducted six trial blasts and concluded that the difficulties encountered outweighed the advantages of the method.

The main disadvantages were a shaft bottom which sloped down towards the diameter which formed the sump boundary. This made it difficult to mount the jumbo and the semi circular face made for a congested work place which led to inefficient rock drill utilization. Achieving the required advance in the leading half of the shaft also proved problematic.

3.8 Concrete Lining of Rockpasses

In the West Witwatersrand mines have been plagued by wearing away and collapse of the rock passes that serve as conduits to the shaft loading pocket. When one cannot get the rock out of the mine the shaft fails to fulfil its main purpose.

In order to prevent this, mines have lined the rock passes. It was also planned to do this at South Deep.

The critical path on station development runs through the access to the rock pass positions. At the tip position a pit is excavated to accommodate the final tipping arrangements. The raise borer is set up in this pit to drill the rock pass 3,1 metres diameter to the next level down. This is all done concurrently with the sinking.

After raise boring and the tip civils are complete the rock pass is set up for concrete lining.

A compressed air winch is set up on the tip steelwork and a 2 deck mobile platform is built in the hole. The upper deck is for making safe/spraying fibre reinforced shotcrete on the walls of the rock pass and the lower for installing rail sets [3 metre] on the rock pass floor for the platform to slide on.

The rock pass is so made safe from the top to the bottom.

When the platform reaches the bottom the concrete lining starts and is done from the bottom back to the top.

The shuttering used for the casting of concrete is a fibre glass sacrificial shutter of 1,5 metres in length with a flat base which fits on top of the rail sets.

Concrete is mixed on surface passed down the slick line to the level. On the level the concrete is pumped to the rock pass and down it behind the shuttering.

The lining rate is of the order of 0,5 metres per day overall.

Many problems were experienced, as the mix is not user friendly, due to the aluminia cement products being used in the same pipelines as OPC ranges of cement. It is very stiff and we often have blocked pipes. In addition, the free fall slicking of the product to a depth of nearly 3 000 metres is breaking new ground with reference to cement transport technologies.

The planned concrete strength was 70 MPa and we achieved as high as 80 – 100MPa. We have lined 320 metres of rock pass to date.

4. Conclusion

Shaft Sinking is Cementation Mining – Skanska's core business.

The urgency attached to sinking and the challenges this type of work brings requires the project team, client and contractors focused attention in order to meet the project schedule and conclude the project successfully.

At South Deep we have had our fair share of challenges and to date we have overcome them all and we look forward to the conclusion of the project in 2003.

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6. List of Figures

7. List of Tables