

# SHAFT SINKING THROUGH HIGH WATER BEARING ROCKS

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## ABSTRACT

The sinking of shafts through water bearing rocks and particularly dolomite has always been a hazardous undertaking. The greater part of the Witwatersrand gold bearing conglomerates are overlain by the Transvaal dolomites and several shafts and mines in the early gold mining days were lost due to influx of uncontrollable quantities of water. This paper describes the principles and practices which have been developed over the years by the South African Shaft Sinking industry which have enabled gold to be won under some of the most arduous severe geohydrological conditions encountered in mining.

## 1. INTRODUCTION

To ensure the cost effectiveness of specialised mechanical equipment and skilled personnel such as is used during shaft sinking, an uninterrupted sequence of operations is therefore planned to achieve optimal performance. Due cognisance must therefore be paid to preventing water ingress into the shaft. This is particularly the case when the shaft traverses water bearing formations.

## 2. PRE CEMENTATION

Diamond drilling and its application to mines in the RSA dates from 1890. The first pre-cementation hole was drilled in the sinking of the Harmony shaft in June 1957.

From 1957 onwards it became standard practice to site test in conjunction with pre-cementation or grouting all shafts in water bearing areas. The idea of a central test hole defining geological conditions has however not been widely applied. The concept does however have the advantage of providing shaft protection as well as defining geological structures.

At Elandsrand situated 80 kms west of Johannesburg two shafts at Elandsrand namely the man/material (M/M) 8.35 m diameter, and rock/ventilation (R/V) 9.78 m diameter, shafts were sited well within and above a gravimetrically determined 200 metre "safe-limit" contour of the northern slope of the Gatsrand. Two pre-cementation holes were drilled in close proximity to the shaft sites. During sinking cementation holes were kept within a 9 metre annulus round each shaft to seal any water bearing pockets in the proximity of the excavation during sinking through the overlying dolomites. (Ref Fig 1 & 2).

## 2.1 Casing of the Pre-Cementation holes

114mm casing were set throughout the upper shales in both holes. 76mm casings were set at 205 metre depths and 60mm casings at 830 metre depths. The reason for setting the casing as deep as possible was to increase the theoretical pre-split pressure at the base of the casing, to reduce the amount of re-drilling of cement, and to gain better control of the direction of the boreholes by drilling 76mm size holes. All casings were grouted in by lowering them to within 10cm of the bottom of the holes, attaching the grouting range, pumping water to establish a circulation down the inside of the casing and up between the casings and the holes, then pumping the final grout in which the casings were set, when the thick grout was seen to return to surface the injection was terminated, the casings lowered to the bottom and a setting period of three days allowed. Casing grout used has a cement, water ratio of 2 : 1 (as thick as the cementation pumps could handle).

## 2.2 Deflections

Hole No. 1 (Fig. 2) serving the M/M shaft was collared 22m from the shaft centre, in order to accommodate sub-bank constructing. There were two phases in controlling the direction of this hole, the first being to guide the borehole into position (9m annulus) and the second to maintain it in that position. For the former, in particular, it is advisable to have a definite plan of action which should include a specific target point marking the end of each phase. In the case of hole No. 1 the aim was to have it back into the 9m annulus when reaching the dolomites at 340m below collar.

In planning holes No's 1 and 2, the natural drift was estimated from the behaviour of holes drilled in the surrounding area. The selection of target points was influenced by the fact that control in phase two would be easier within the line where the natural drift in the dolomites was tangential to the stipulated limits, a circular zone extending from five to fifteen metres from the shaft centres. These limits ensured that the holes, and in particular any casing, wedges or rods left in the holes, remained out of the shaft sinking operational area that followed and yet placed injections close enough to be completely effective.

## 2.3 Re-drilling

Re-drilling was done using non-coring tungsten carbide crowns and limiting the life of each crown to 200 metres. Drilling further than this resulted in the necessity for reaming or even having the crown stuck in the hole.

## 2.4 Decisions when to inject

The decision was taken to inject when significant water loss occurred during the drilling operation.

With a water loss of 50 percent or more the hole was injected at the completion of a run. When smaller losses occurred, the hole was drilled on to determine if the loss increased (this was normally the case) the ruling was that not one of the holes would be continued for more than fifty metres with a partial water loss without taking a pressure test to establish the flow which the hole would accept under pressure.

## 2.5 Grouting procedure

When the decision to inject had been made it became standard practice to measure the water level in the hole and where applicable, to do a water pressure test. It was standard practice that by the time an injection was started in one hole, the rods should at least be in the process of being pulled from the other. On only one occasion an injection inter-connected between the two holes. At the start of each injection clear water was pumped for one hour in order to flush the fissure, to clear drill chips from the hole and to create a flow within the fissure.

A starting mix with a water, cement ratio 6 : 1 (density 1,10) was used. Depending on the course of the injection, the density of the mix should be increased at four hourly intervals by 0,05. Sealing pressure used was 40 bar. This was based on the fact that pressures tended not to increase above that level due to the fast pumping rates and the increase in pressure at the point of injection imposed by the column of cement mix in the hole. Although this pressure was well below the theoretical pre-split level at the base of the casing it is always considered necessary to be aware of the maximum.

Injections were terminated by pumping 800 litres of cement with a density of at least 1.50 followed by a calculated volume of water sufficient to clear the casing.

## 2.6 General

The stated intention of the pre-grouted holes was to pump cement ahead of the shaft sinking operations, in order to seal off any water bearing zones, to improve ground conditions and to provide geological information which could assist with shaft and station planning. Logging of the shafts indicated clearly that cement had permeated the area and cement grout was consistently detected in both shafts.

It is apparent that in pre-cementation from surface considerable wastage may occur due to pumping cement into dried out fissures which would not adversely affect sinking. This is an unavoidable risk which must be accepted. Experience gained to date indicates that the practice of pre-grouting from surface may well prove of inestimable value in reducing sinking delays due to water intersections. It is however, imperative that pre-cementation holes be started well ahead of the commencement of sinking. The ideal would of course be to have pre-grouting complete before any shaft sinking commences. Pre-cementation does not however guarantee that major water intersections will not be encountered during sinking operations. The frequency of intersections should however be significantly reduced.

# COVER DRILLING AND CEMENTATION DURING SINKING

## 3.1 General

As mentioned previously one cannot rely on pre-cementation holes only and it is therefore imperative that cover drilling should be done on all shafts being sunk. The procedures set out below for cover drilling and cementation of shafts have been used very successfully and could be viewed as a guide to assist those who are involved in the sinking of shafts.

## 3.2 Primary Cover Round

### **3.2.1. Design**

The standard primary round design should be such that all the holes drilled will intersect a point approximately 6 metres outside the shaft excavated diameter at the projected drilling depth and radially in line with the collar of the adjacent clockwise hole (Ref Fig 8). The design must ensure that one or more of the holes will intersect the plane of any randomly orientated water bearing fault or fissure in the ground ahead of the shaft being sunk. The 6 metre projected point is of extreme importance as any distance closer than 4,5 metres to the excavation line might suffer blast damage and result in leakage from fissures sealed previously. The design length of the round is also important in that the longer the round the bigger the possibility of deflections and inaccuracies resulting there from. It is recommended that the length is varied in order to match a six day sinking rate and to facilitate cover drilling and possible grouting on the seventh shift. An overlap of at least 6 metres is required between successive cover rounds in order to ensure that sinking will take place into untested ground.

On completion of the Cover Round all holes are to be grouted and sealed irrespective of whether or not water was intersected. Only in the event of a completely dry cover round, or a total water make of < 1,5 litres / min should sinking continue, and only with approval of the client.

## **3.3 Secondary Cover Round**

In the event of the primary standard cover round intersecting water and subsequent to sealing, a secondary cover round consisting of the same number of holes as the primary round is to be drilled to check the success or otherwise of the grouting procedure. These holes are to be similar in all respects to the primary cover round except that the holes are to be located mid-way between the previously drilled round, 500 mm radially inward from the shaft perimeter and with a similar but with an anti-clockwise spin. On completion of the secondary round all holes are to be grouted and sealed irrespective of whether or not water was intersected.

Only in the event of negligible water i.e. < 1,5 litres per minute being encountered in the secondary cover round, should sinking proceed, and then only with the approval of the client and the carrying of four pilot holes ( 1,5 times the length of the round) ahead of the excavation.

## **3.4 Tertiary Cover Round**

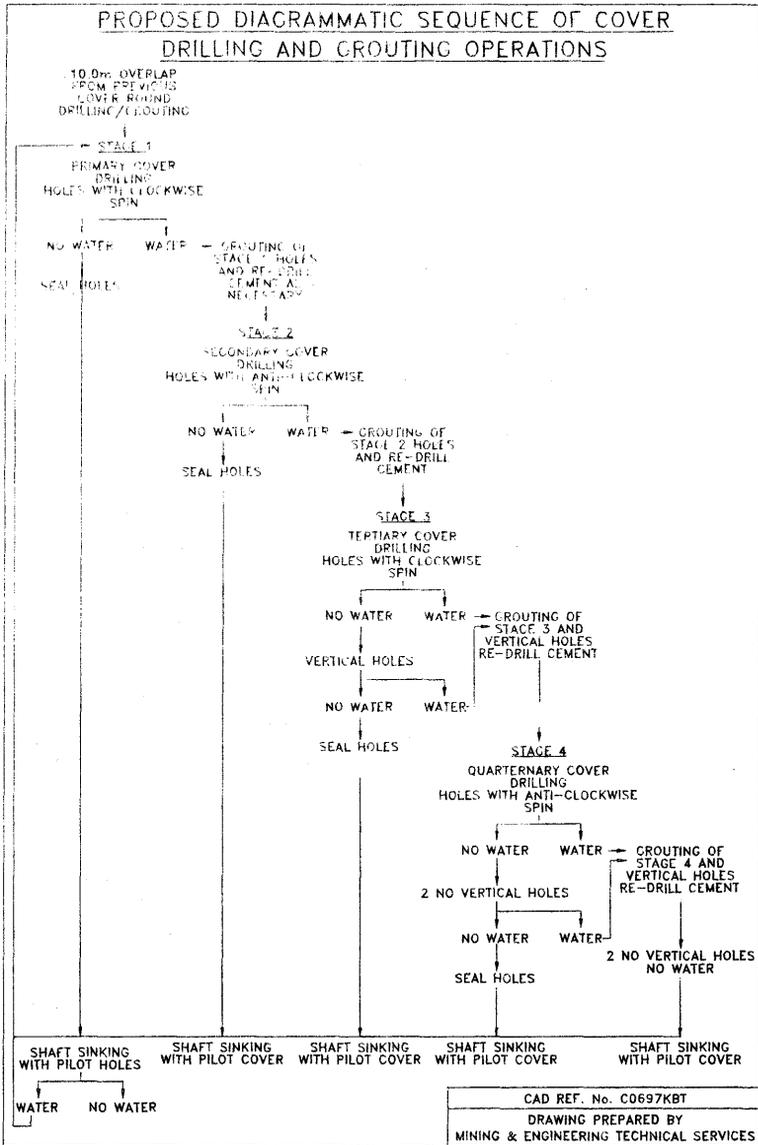
In the event of significant water, > 10 litres per minute, being encountered in the secondary cover round, and subsequent to sealing thereof, a tertiary cover round consisting of the same number as the primary and secondary rounds is to be drilled to check the success or otherwise of the secondary grouting procedure. These holes are to be similar in all respects to the primary round except that the holes are to be located on the shaft perimeter mid way between the primary cover round holes and with an identical clockwise spin. Only in the event of negligible water encountered in the tertiary cover round and the drilling of two dry vertical cover holes +/- 2 metres from the shaft centre line should sinking proceed after grouting the holes and with the approval of the client. It is also recommended that four pilot holes ( 1,5 times the length of round) be carried ahead of the excavation.

## **3.5 Quarternary Cover Round**

In the unlikely event of either the tertiary cover round or the two vertical holes, drilled

of shaft centre, indicating significant unsealed fissure water ahead of the planned excavations a quarternary cover round may be required. The quarternary round should comprise of the same number of holes and design as the original primary round except the holes should be located mid-way between the secondary cover holes, 500 mm in from the perimeter, and again with an anti-clockwise spin.

On completion of the quarternary round all holes are to be sealed irrespective of whether or not water was intersected. It is recommended that two vertical holes be drilled  $\pm 2$  metres from the shaft centre line on completion of the procedures outlined above to test the effectiveness of the quarternary grouting procedures. In the most unlikely event of water being intersected in the vertical holes the client may require additional stages of cover drilling and grouting. On completion of the above sinking should include the drilling of 4 pilot holes ahead of the excavation.



## 5.0 Action in the event of encountering water

Detailed records must be kept and management must be informed at the earliest convenience of each and every water intersection encountered during the drilling of cover rounds. In the event of any cover hole intersecting a water bearing fissure which delivers more than 8 litres per minute ( $> 500 \text{ l/hr}$ ) drilling should continue for approximately one metre more in order to effectively expose the fissure. The drill rods should be withdrawn from the hole and the water sealed off by means of the drilling valve. The removal of the drill-rod string can be dangerous when large fissures are intersected. The rods should be securely clamped and, if possible, removed gradually. The area above and behind the machine must be cleared of all personnel. Grouting of this hole should commence immediately as detailed in "Grouting of Water Intersections". Drilling of the cover round is to be discontinued in that quadrant of the shaft during the injection of grout or if any of the other holes intersect the same fissure.

In the event of intersecting a "Dirty" fissure the dirty water from the borehole is to be allowed to run freely from the borehole until the water clears or for a period not exceeding 15 minutes prior to grouting taking place.

## 6.0 Grout Pressures

From work carried out by the C.S.I.R using the C.S.I.R. triaxial strain cell, Van Heerden (Ref. Fig 3 & 4) gives the equations to determine the approximate vertical and horizontal geostress at various depths below surface.

Scrutiny of the curves show that down to a depth of approximately 450 m from surface the horizontal geostress component exceeds the vertical geostress component, but that below this depth the reverse applies.

From the point of view of grout pressures and assuming a hypothetical water table at surface, the following conclusions may be drawn:

- (A) It is obvious that the grout pressure must exceed the hydrostatic head in order to induce the grout into any water filled discontinuities.
- (B) From surface down to 450 metres, grout pressures exceeding the overburden or vertical rock stress are assisted by the relatively high horizontal stress and will tend to hydrofracture and infiltrate the horizontal discontinuities in preference to the tighter vertical discontinuities. In a closed system where the discontinuities are gradually being choked off from the water table by the grouting process, grout pressures approaching the overburden pressure must be avoided or surface uplift will occur.
- (C) At depths below 450 metre grout pressures exceeding the horizontal geostress component will hydrofracture the rock in vertical planes and the grout will tend to infiltrate the vertical discontinuities in preference to the tighter horizontal discontinuities. In the +grouting of sinking shafts where grout pressures exceed the horizontal geostress component, the danger exists that the grout will travel upward and may find a path behind the concrete and result in damage to the lining.
- (D) The final choke off pressure during the grouting process from the bottom of a sinking shaft should not exceed the minor principal stress (i.e. vertical stress up to 450 m and horizontal stress of below 450 metres depth) or hydrofracture will continue to well beyond the desired grout curtain and consequent wastage.
- (E) Below the depth of 450 m there is merit in controlled hydrofracture of the rock at pressures slightly above the value of the horizontal stress component at the start of the grouting process. This has the effect of opening up the vertical discontinuities in the immediate vicinity of the borehole and tightening up of the rock around the shaft during the grouting.

From the above it is clear that for normal water control, grout pressures at the grout hole collars should lie within the envelope bounded by the hydrostatic head and the minor principal stress as shown in (Fig. 3 & 4) and that the general rule of assuming 2.5 times the hydrostatic head as the maximum grout pressure should be avoided.

In consultation with the client the pressures at which grout will be pumped, the final choke off pressure, and where necessary the pressures at which hydrofracture is to be carried out will be determined.

## 7.0 Grouting of Water Intersections

The object of grouting is to fill and cement up (resist washout) the fissure or any other feature which has caused a water loss or gain in the cover hole. After removal of the drill string and allowing the water to clear the valve is closed, the stuffing box is to be removed and a connection to the shaft cementation range is made. A by-pass valve and pressure gauge is to be fitted to the casing pipe. (Ref. Fig. 3 & 4)

It is important to record prior to any further activity the following data.

- (i) Shaft Bottom Depth Below Surface
- (ii) Cover Hole Position
- (iii) Depth at which the water was intersected
- (iv) Water Yield in Litres per Minute
- (v) Water pressure (Hydrostatic Head)

Injection / grouting procedure will initially start with filling the surface pump, grout ranges and connections with water after which pumping of clear water will commence during which period the water pressure and acceptance rate of the fissure should be observed and recorded.

For this purpose the number of strokes per minute at the pump, the rate at which the water in the grout mixing barrel drops, or a flow meter at the end of the grout line, together with the pressure gauge may be used. Two or more sets of readings are required to be recorded at this stage:

- (i) Pressure of acceptance  $f_1$ ,  $f_2$ ,  $f_3$  etc
- (ii) Rate of acceptance in litres per minute corresponding to  $f_1$ ,  $f_2$ ,  $f_3$ , etc

A comparison between actual hydrostatic head (e), the yield on drilling (d) and the pressure of acceptance  $f_1$ ,  $f_2$ , versus the rate of acceptance  $g_1$ ,  $g_2$  together with interpretation thereof results in information regarding the characteristics of the fissure. The procedure is limited to the pumping capacity of the cementation pump and the pressure at which hydrofracture occurs.

Figure 6 shows graphically the characteristics of three different fissures. Fissures with high resistance to water acceptance as in AB are required to be sealed with a thin grout mix and should contain a lubricant such as sodium silicate or bentonite. Fissures with low resistance to water acceptance as in AD must be sealed with a thick grout mix.

The main constituents of the grout mix will be bentonite, ordinary portland cement and water and the grout mix design will be composed of any one or more of the following designs on a weight (mass) basis

	<b>Bentonite</b>	<b>Cement</b>	<b>Water</b>
<b>(i)</b>	0.5	10	100
<b>(ii)</b>	0.65	20	100
<b>(iii)</b>	0.80	30	100
<b>(iv)</b>	0.95	40	100
<b>(v)</b>	1.00	50	100
<b>(vi)</b>	1.00	70	100
<b>(vii)</b>	1.00	90	100

Other additives such as sodium silicate, or dyes may be used in consultation with the client.

For high resistance to water acceptance fissures, injection will start with grout design (i) above and gradually in stages proceed toward grout design (vii) or until pressure build up to the required value is experienced.

Low resistance to acceptance fissures will be injected with the thicker design mixes depending on the fissures characteristics.

The procedure may be summarised as follows:

- (A)** Start with the clear water injection.
- (B)** Taking the characteristics of the fissure into consideration, start cement grout injections using cement grout mix designs as listed above.
- (C)** Once a pressure increase is registered the mix should be maintained at current level for 4 hours. If no pressure increases occur then increase the mix after 4 hours with a density increase of 0,05/4 hours.
- (D)** If a pressure drop occurs increase the density of the mix immediately.
- (E)** If there is no increase in pressure after protracted pumping at 1:1 (say 24 hrs) then 2 alternatives are available:
  - (i)** Slow down the rate of pumping, if the pressure is still not attained, then pump for one hour, and switch off for one hour. The idea is to get the cement to settle out and then pump it as a plug into the fissure.
  - (ii)** Another recommended method is to increase the mix further to 1:2.
- (F)** Once a sealing pressure is reached, drop to a slow rate of pumping for the final seal.
- (G)** Inject clear water to clear the pump, ranges and casing head of cement at sealing point.
- (H)** Switch pumps at regular intervals to allow routine cleaning of valves and inspection for wear on liners. This will prevent clogging and premature sealing.

## 8.0 Equipment Specifications

### 8.1 Cementation Ranges

A minimum of 2 x 25 mm cementation ranges should be carried with other shaft services. Only high pressure table 80 seamless pipes are recommended. Before commencing with

grout injection the cementation ranges should be extended to within 2 metres of the shaft bottom. During grout injection 10,0 x 25 m high pressure rubber hoses should be used as connections between the cementation ranges and cover hole casings. After every injection period all cementation ranges should be properly flushed with clear water.

## **8.2 Casing Pipes**

Casing pipes should be thick walled, high pressure with an internal diameter of 50 - 52,8 mm. The ends of the casing pipes to be chamfered internally to prevent fouling of rod couplings. The casing pipes should be spot welded on the outside and sandblasted to increase adhesion when grouted in. To a depth of 1000 metres below surface casing pipes should not be less than 2,5 metres in length. A depth greater than 1000 metres below surface the casing length should not be less than 3,5 metres.

### **8.2.1. Casing Installation**

Before commencing with the casing installations the shaft footwall and sidewalls to be examined and certified free of misfires.

If use is made of a Sinking Jumbo this will be lowered and placed in position, alternatively the drilling rig be placed in position, levelled and anchored (see fig). The drilling machines shall be placed, clamped and set by a surveyor according to the required design.

Casing holes, 89 mm in diameter will be collared and drilled to the required depth. Casing pipes will be grouted-in using cement grout or a quick setting resin.

After allowing a setting period of 4 hours all holes will be re-drilled using a 50 mm drill bit to a depth of 5 metres. A hydraulic test using dye added to water to be undertaken on every casing to determine and ensure that no leakage would occur.

Test pressure should be in excess of sealing pressure calculated previously. Once all the casings have been pressure-tested, drilling may begin.

## **9.0 Conclusion**

In the construction of any new shaft it is imperative to do pre-cementation despite whatever geological conditions exist. The treatment of water has and will always remain a major problem to mining engineers. A lead period of a least 2 years would be required for pre-cementation of a deep shaft system. The temptation will always be there to become impatient because of the time and finance involved in the carrying out of the pre-cementation and cementation operations during sinking. This should be avoided at all cost, by speeding up the above process and thereby plugging fissures rather than sealing them would not only result in high pumping cost of residual water but could result in disastrous consequences of expensive rescue operations or the abandonment of a project.

## **APPENDIX 1**

### **SUMMARY OF COVER DRILLING PROCEDURE**

1. Stop sinking or development when 10 m of previous cover is left.
2. Examine shaft bottom or working face for misfires.
3. Position and anchor drill rig / Lower sinking Jumbo.
4. Align and Surveyor to check.
5. Drill 89 mm casing holes to required length.
6. Install casings.
7. Set casing for 4 hours.
8. Drill box girder holding-down wedge bolts (1,5 m x 30 mm)
9. Install high pressure cementation valve and T-block with HP bypass on casing.
10. Anchor down with box girder and 1,5 m x 30 mm wedge bolts.
11. Re-drill casing to a depth of 5 m with a 51 mm bit
12. Pressure-test hole to a maximum pressure calculated using water and coloured dye
13. Test installation by closing bypass and stuffing box and open drilling water to see whether the drilling equipment is watertight.
14. In case of a leak, cement must be injected and sealed. Set and test to be repeated after 4 hours.
15. After double checking all holes for leaks, drilling may commence
16. When water is intersected the stuffing box must be closed immediately and then the stuffing box bypass must be closed. If the problem occurs that the water cannot be controlled, the rods must be pulled as quickly as possible and the drilling valve on the casing must be closed. In each case management must be notified.
17. All water intersections must be cemented and re-drilled until no water is made on re-drill. Dye could be used to identify injections.
18. Dry holes must be cementated but need not be re-drilled.
19. Measure water quantities.
20. All water intersections must be pressure-tested and the results must be logged.
21. A daily cover drill and cementation report to be kept.
22. An additional book to be kept showing daily information concerning cover drill.
23. The project geologist is to inspect and sign cover drill books daily.
24. An emergency car and emergency cementation board should be maintained at all times.

## **APPENDIX 2**

### **EMERGENCY CEMENTATION BOARD**

- 5 x 35 mm telescopic pipes with valves.
- 5 x 25 mm drive pipes with valves.
- 20 steel wedges (as per car specifications).
- 20 softwood wedges ( as per car specifications).
- 6 x 0,6 m x 25 mm eyebolts.
- 1 x 1,8 kg hammer.
- 1 x 14" Stilson wrench (RIGID).
- 1 x 24" Stilson wrench (RIGID).
- 2 x 25 mm HP tee-piece blocks.
- 2 x clamps for 25mm drive pipe with nuts and bolts.
- 2 x clamps for telescopics with nuts and bolts.

## **APPENDIX 3**

### **EMERGENCY CAR**

Contains the following equipment:

- 2 x 3 sheave rope blocks with 25 m of rope each.
- 2 clamps for 50 mm pipes with bolts and nuts.
- 2 clamps for 32 mm pipes with bolts and nuts.
- 2 clamps for 25 mm pipes with bolts and nuts.
- 10 x 25 mm x 38 mm (1" x 1½") reducing brushes.
- 10 x 32 mm x 50 mm (1¼" x 2") reducing brushes.
- 10 x 25 mm x 50 mm (1" x 2") reducing brushes.
- 10 x 38 mm x 50 mm (1½" x 2") reducing brushes.
- 6 x 38 mm x 4 m tapered d/pipes (taper over 150 mm).
- 6 x 32 mm x 2 m pipes (threaded both ends) with coupling.
- 6 x 32 mm x 4 m pipes (threaded both ends) with coupling.
- 12 x 32 mm x 0,3 m tapered pipes (taper over 150 mm).
- 6 x 25 mm x 2 m pipes (threaded both ends) with coupling.
- 10 x 25 mm x 3 m pipes (threaded both ends) with coupling.
- 20 x 25 mm 0,3 tapered pipes (taper over 150 mm).
- 8 x 100 mm shackles.
- 6 x 25 mm x 0,6 m eyebolts.

- 6 x 25 mJm or 32 mm wedge bolts and nuts.
- 50 x 19 mm x 150 mm steel wedges.
- 20 x 25 mm x 25 mm x 300 mm steel wedges.
- 100 x 75 mm x 100 mm x 400 mm wooden wedges.
- 100 x 38 mm x 28 mm x 225 mm wooden wedges.
- 5 x 9.5mm x 2m long link chain.
- 20 x 13 mm x 100 mm square washers. (Hole to suit o.d. of wedge bolt).
- 6 x 25 mm HP valves.
- 6 x 38 mm HP valves.
- 6 x 50 mm HP valves (red).
- 12 x 25 mm steam nipples.
- 4 x 25 mm tee-pieces.
- 10 x 38 mm steam nipples.
- 10 x 50 mm steam tee-pieces.
- 2 x 38 mm HP tee-piece blocks.
- 4 x 25 mm HP unions.
- 4 x 50 - 38 mm female - male HP adaptors.
- 4 rolls of ventilation membrane.
- 1 bag sawdust.
- 1 hacksaw with 20 highspeed blades.
- 1 boxesaw with 10 blades.
- 2 x 1,8 kg hammers with handles.
- 1 x 7,2 kg hammer with handle.
- 2 x 24" Stilson wrenches (RIGID).
- 2 x 18" Stilson wrenches (RIGID).
- 2 x 14" Stilson wrenches (RIGID).
- 4 x 3/4" flat ring spanners.
- 2 x 12" shifting spanners.
- 2 marlin spikes.

## 10. Acknowledgements

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By George W Holl Prof. Eng. and Norman D Harte BSc. Hon. Consultant to L.T.A. Construction Ltd.

Engineering Geologist to Shaft Sinkers (Pty) Ltd.

FIG 1

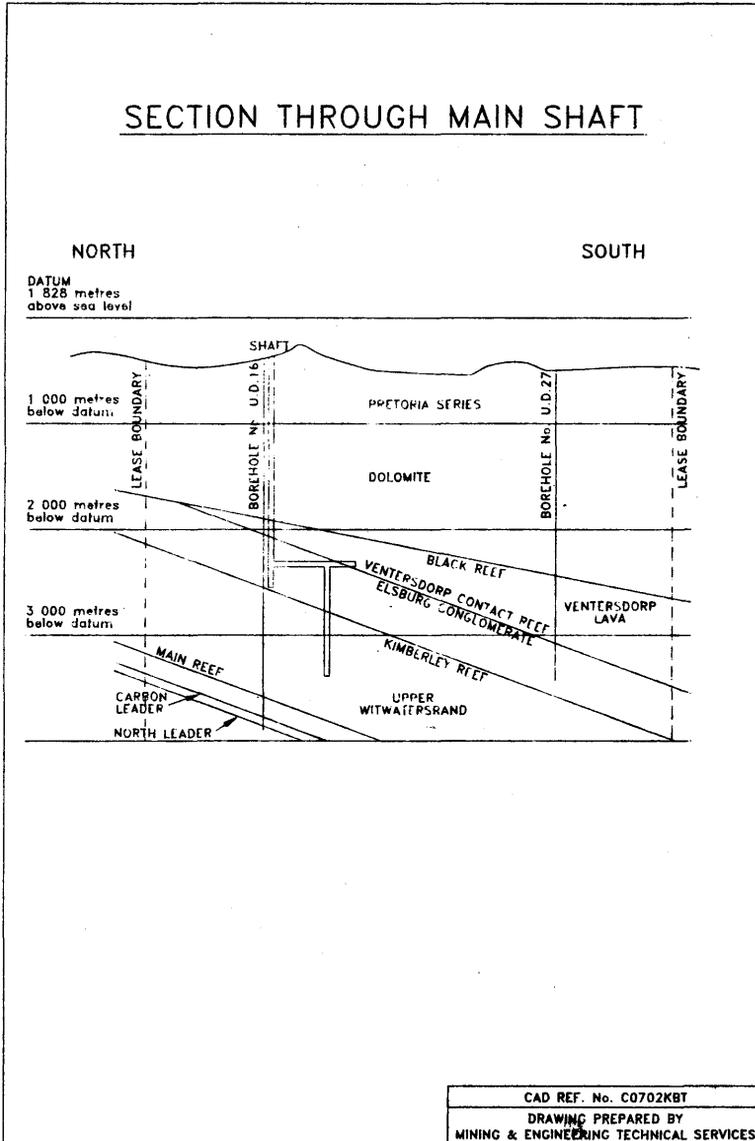


FIG 2

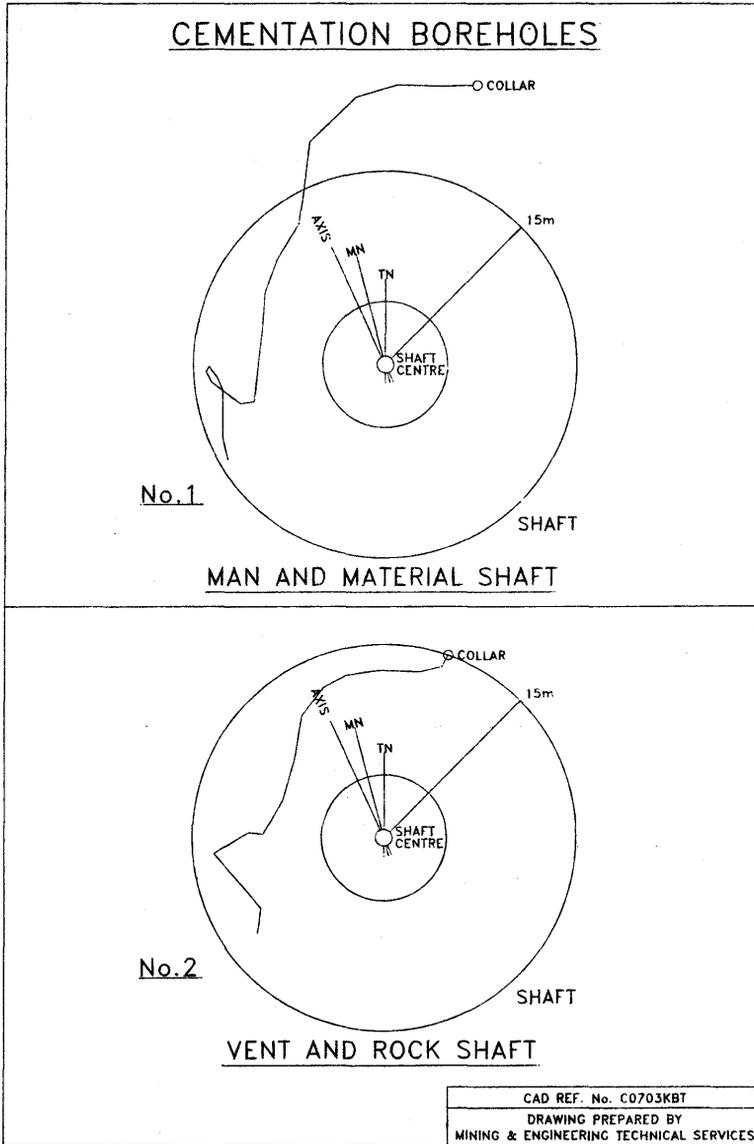


FIG 3

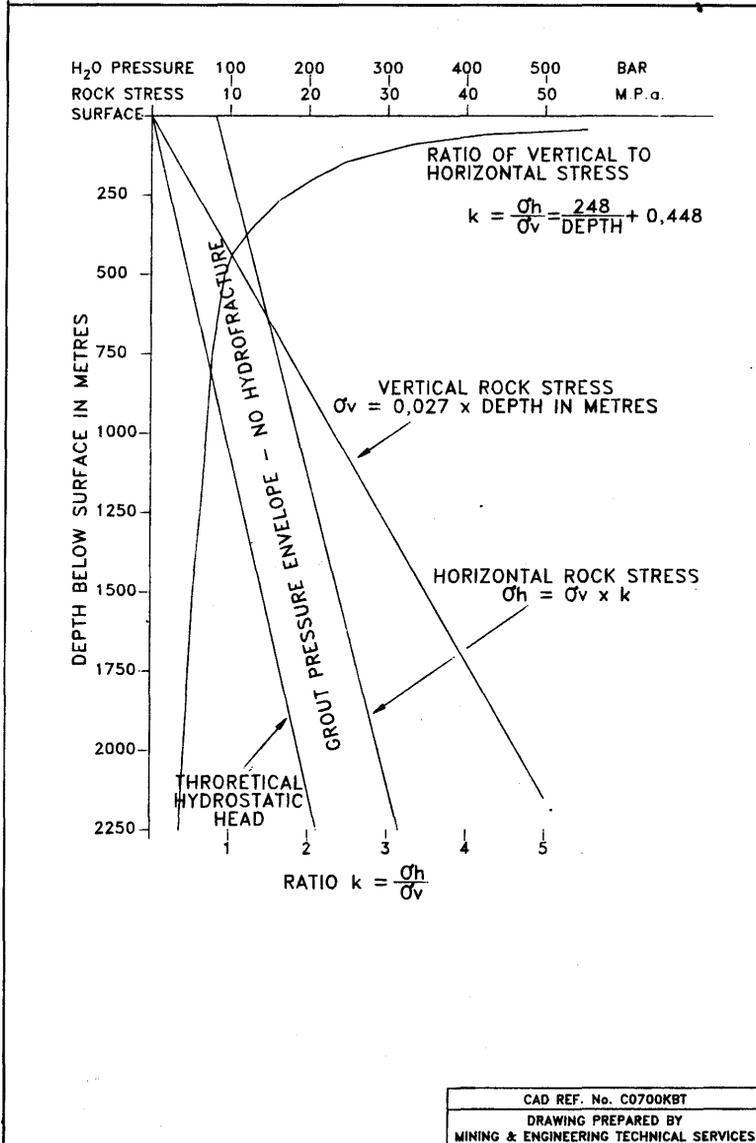
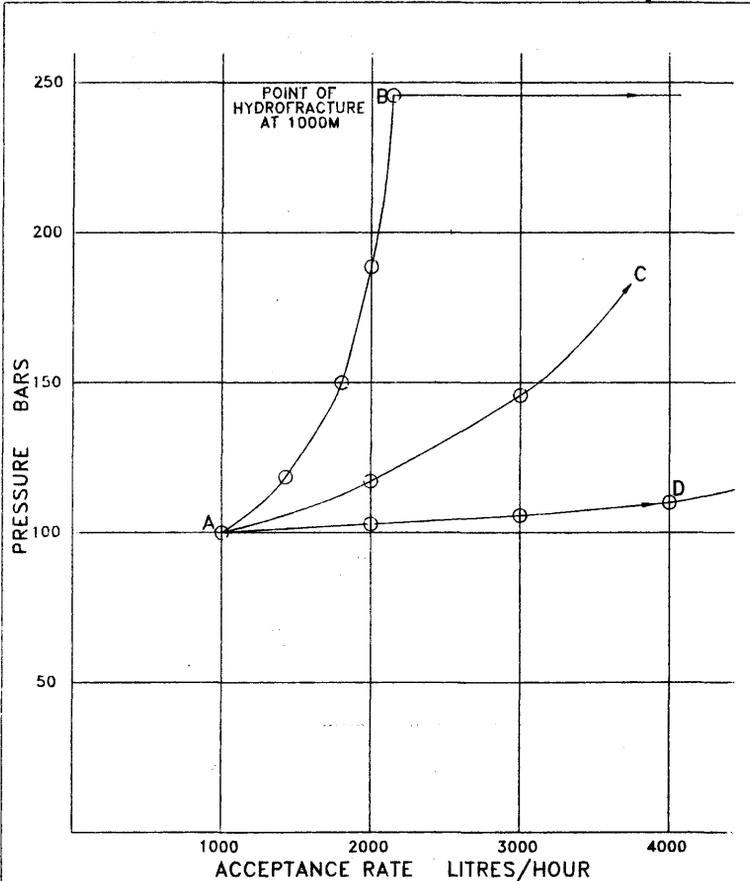






FIG 6



**IDEALISED PRESSURE-ACCEPTANCE CURVES  
FOR A COVER HOLE AT A DEPTH OF 1000M  
DELIVERING 1000 LITRES/HOUR**

- CURVE A.B. FISSURE** WITH HIGH ACCEPTANCE RESISTANCE  
THIN GROUT MIX REQUIRED AT START OF INJECTION
- CURVE A.C. FISSURE** WITH MEDIUM ACCEPTANCE RESISTANCE  
MEDIUM GROUT MIX REQUIRED AT START OF INJECTION
- CURVE A.D. FISSURE** WITH LOW ACCEPTANCE RESISTANCE  
THICK GROUT MIX REQUIRED AT START OF INJECTION  
TO SEAL FISSURE

CAD REF. No. C0698K8T
DRAWING PREPARED BY MINING & ENGINEERING TECHNICAL SERVICES

FIG 7

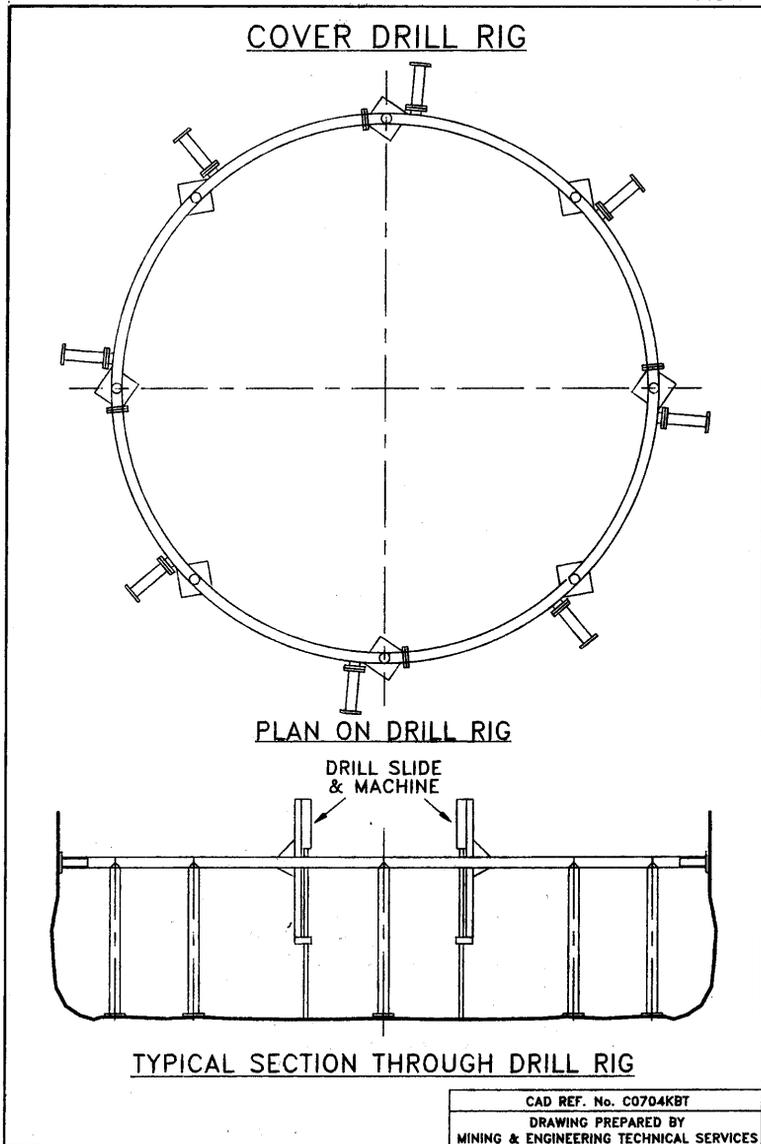


FIG 8

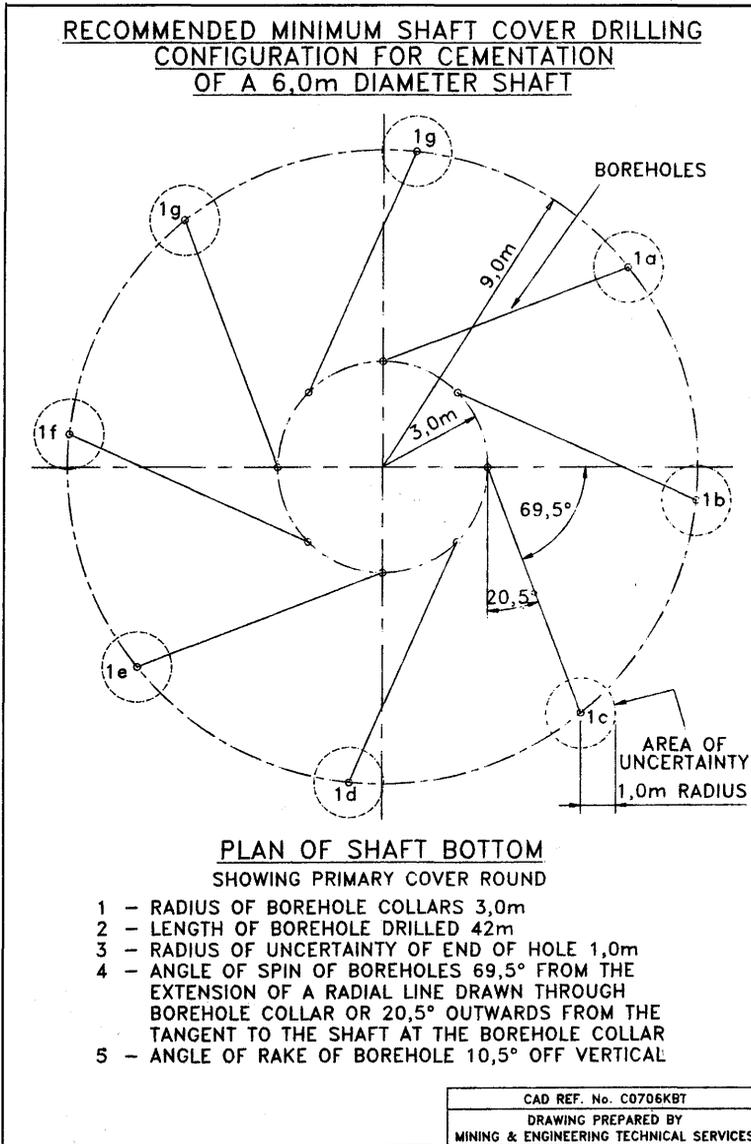


FIG 9

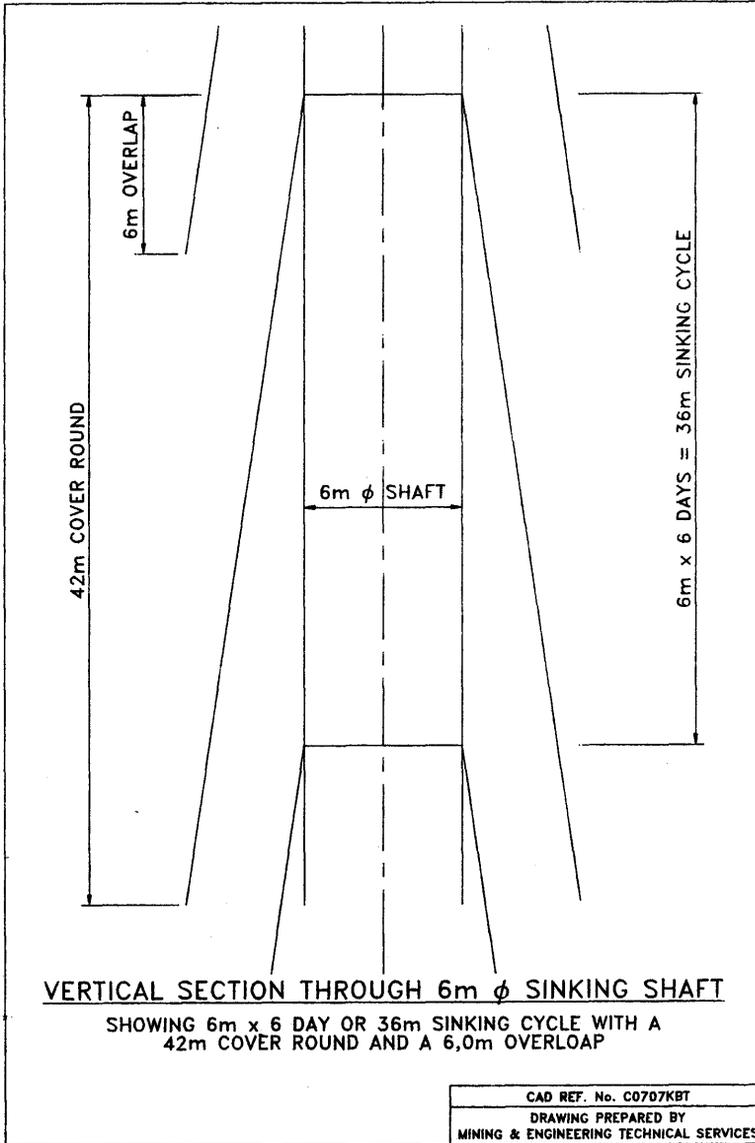
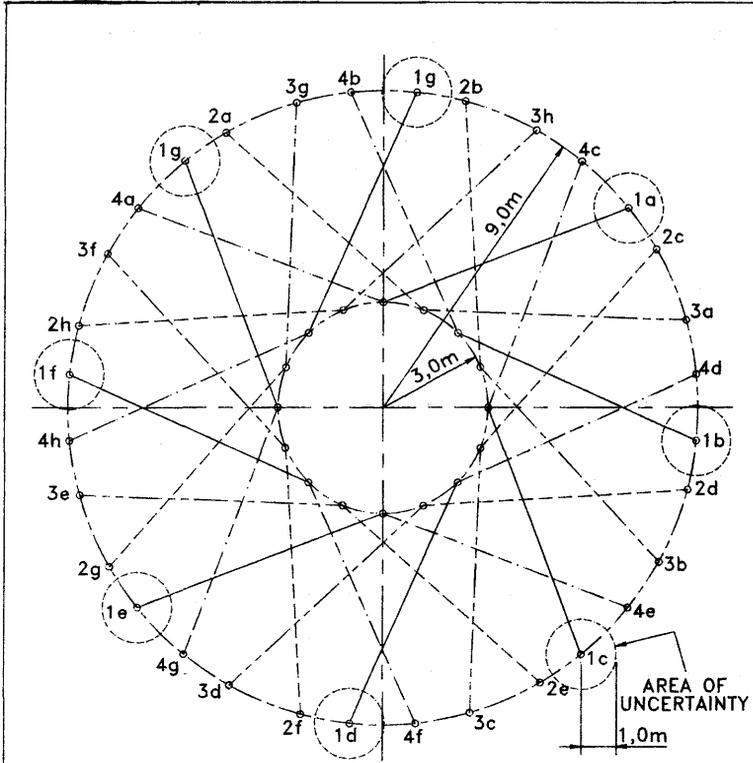


FIG 10



**PLAN ON A 6,6m EXCAVATED DIAMETER SHAFT**

SHOWING.

- |                                     |          |
|-------------------------------------|----------|
| 1 - 8 HOLES PRIMARY COVER ROUND     | 1a TO 1h |
| 2 - 8 HOLES SECONDARY COVER ROUND   | 2a TO 2h |
| 3 - 8 HOLES TERTIARY COVER ROUND    | 3a TO 3h |
| 4 - 8 HOLES QUARTERNARY COVER ROUND | 4a TO 4h |

RADIUS OF BOREHOLE COLLARS	3,0m
RADIUS OF BOREHOLE TOE	9,0m
RADIUS OF AREA OF UNCERTAINTY DUE TO BOREHOLE DEFLECTION	1,0m

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