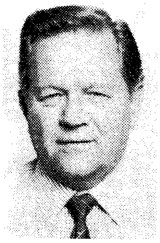


THE FLOODING OF WESTERN DEEP LEVELS NO.1 SHAFT

R. L. de G. SOLMS

MINE MANAGER, WESTERN DEEP LEVELS LIMITED (SOUTH)

I N D E X

WESTERN DEEP LEVELS LIMITED (SOUTH)
FLOODING/DE-WATERING NO.1 SERVICE SHAFT

1. INTRODUCTION

Although two pre-cementation holes were drilled from surface, one adjacent to each shaft, and normal shaft-sinking eight-hole cover rounds were drilled ahead of shaft sinking, a major inrush of water occurred in July of 1982.

This paper describes the flooding and subsequent recovery of the shaft, but the three most important questions that need to be answered are:-

a) Why did the pre-cementation and cover holes not locate the water?

b) Why was water intersected in a de-watered compartment?

c) What precautions are being taken to prevent a recurrence?

2. FLOODING

On the night of the 9th July, 1982, when the shaft was at a depth of -970 metres below collar and while preparations were being made to lash a blasted round, a long slab of the sidewall approximately 3 metres long and 2 metres in height broke away and partially heaved over in the shaft. See Figure 11.

Shortly thereafter, water started to rise quickly, covering the shaft bottom. The Sinker put all the available Quimby pumps into action, pumping into the kibbles. Ten pumps were eventually in use but the water level continued to rise.

2. FLOODING continued ...

A large submersible pump was prepared for placement into the shaft below the stage. While the necessary electric cables were being prepared, the kibbles were converted into bailers, by cutting flaps into their bottoms.

With the submersible pump operating and all the kibbles bailing, the water was still rising at ± 1 metre per hour. When all pumping and bailing was stopped to determine the rate of inflow, the water level rose at 5 metres per hour, giving a calculated inflow of 126 litres per second (100,000 gallons per hour).

Since the shaft pumping system, which consisted of 2 MPB 5 pumps placed in chambers every 300 metres in the shaft, pumping in series to surface, could only handle 53 litres per second, it became clear that placing more pumps into the shaft bottom would serve little purpose. If pumping was to keep the water level at bay while attempts were made to seal the source, then the pump stations would have to be enlarged. Larger pumps, power cables and large diameter pipes would also have to be put into the shaft.

Previous experiences of trying to pump down against a large inrush of water had proved ineffectual and incapable of achieving success. The stopping of the pumps to extend the pipes permits the water level to rise to its previous level before the pipes can be completed, thus defeating the effort.

Water inflowing through the Dolomites tends to leach out any solids in the conduit and also enlarges the orifice concerned. The rate of inflow could thus increase until the pumping capacity is neutralised. The whole exercise

2. FLOODING continued ...

would then have to re-start with bigger pump chambers, etc. For this reason it was decided to allow the water to rise to its natural level. With no flow at the point of the inrush, two options to seal the 'fissure' were then available.

Firstly, by pumping water back into the shaft a counterflow could be effected. If a suitable grout could be injected at this point, it would flow into the 'fissure' and possibly seal it.

The second option would be to cast an underwater plug, pump the water out and then drill and inject the total area around the plug. The plug could then be removed and sinking resumed.

Although the first option seemed feasible and attractive its probability of success was doubtful. There would be no way of determining exactly how far the grout had penetrated the 'fissure' or how strong a seal it would provide. While lowering the water to the plug by pumping, the pressure on the plug would progressively increase. It was feared that the 'plug' would blow out like a cork when the pressure got too great and the shaft would again flood.

The second option (casting an underwater plug) had been tried with success at Blyvooruitzicht in 1937 in a rectangular shaft, and again in 1953 at Free State Geduld, also in a rectangular shaft. Little documentation of the precise method used was available but discussions with the people who were involved convinced us that this had the best chance of success.

3. THE PLUG

Gold Fields Cementation Company, who had both experienced staff and many years of operating in the Far West Wits Dolomite Region, were contracted to design and install an adequate underwater plug. See Figure 12.

In constant discussion with the Project Team and as many experienced 'experts' as was possible, they finally commissioned the Civil Engineering Department at the Witwatersrand University to design the plug. Professor Blight determined that a plug of 17 metres length in the 10 metre diameter shaft would have a safety factor of 5:1 even if the plug strength was no greater than 5MPa. Because he assumed a homogeneous shaft lining and had to consider only a theoretical solution, Mine Management decided to increase the plug length to 27 metres, leaving nothing to chance. See Figure 13.

To ensure that the grout mix remained dense enough to set in the shaft bottom, it had to be placed into the water in such a manner that it would displace the less dense water. The method decided upon was :-

a) To lower five clusters of three 25mm pipes, clamped to a 22mm rope, to the shaft bottom by means of the kibble hoist ropes. This was to be done using the inside of the air, concrete and ventilation pipes that were already in the shaft. They were to guide the clusters to within 20 metres of the shaft bottom.

b) Plumbs of waste rock were then to be tipped into the shaft to form the body of the plug.

3. THE PLUG continued ...

c) The grout would then be pumped into the ranges from surface, until it rose above the top of the plumbs. The plug would then be allowed to cure for a suitable period.

d) The water was then to be pumped out of the shaft by lowering Pleuger pumps under the stage until the top of the plug was reached.

e) The plug would be tightened by means of drilling concentric patterns of holes through which grout would be pumped to a pressure exceeding the static head of the water.

f) Sinking would then resume.

4. THE FIRST ATTEMPT

The 25mm ranges were clamped to a 22mm diameter rope that was in turn spliced into the hoist rope. The clamps were spaced every 100 metres apart and the pipes were banded to the rope at more regular intervals between the clamps. See Figure 15.

The ranges were lowered into the pipe columns in the shaft, one at each point of the compass. The last was to be lowered into the centre of the shaft. The first range was lowered into a 200mm compressed-air pipe without problems. The second rage was placed into a 150mm concrete pipe, also with little trouble, although it stuck once or twice. The ropes were tied off in the headgear.

While lowering the third cluster into a 1 118mm

4. THE FIRST ATTEMPT continued ...

ventilation column problems occurred. Six hundred metres of the range had been lowered when, with a resounding bang, the range 'ran-away'. The rope was still intact although taut. It appeared that the pipes had slid off the rope despite the fact that a swedged foot-piece was at the bottom of the rope.

The first concern was whether the pipes had run all the way to the bottom of the shaft or whether they were hung-up somewhere in the shaft under the water.

The stage was lowered and the ventilation pipe was cut open at 50 metre intervals. At ± 320 metres down the column the pipes were found to have 'bird-caged' in the ventilation pipe. Over one hundred pipe lengths, now like a bunch of spaghetti, were cut out of six lengths of the ventilation pipe. Immediately below the clamp that had held the 'bird-caged' pipes the rope had snapped and it was assumed that the remaining pipes were in the bottom of the shaft. Once again concern was expressed that the remaining pipes might be hanging into the shaft. If so, any attempts to lower further ranges could foul these pipes.

Because of mass of the cluster being lowered it would be impossible to 'feel or tell' if the pipes got stuck in the shaft. They would simply bend and one would believe they had reached their destination. Grouting of the plug would then be an absolute failure. The problem was how to find out whether the pipes were in the shaft bottom or not.

An Engineer was flown out from the British North Sea Oil Rig to advise on the possibility of lowering divers to

4. THE FIRST ATTEMPT continued ...

such depths. It was discovered that diver-type suits were available that would permit a man to descend to the shaft bottom to inspect the damage. This method would of course have proved extremely expensive, since a back-up diver plus a full operating team of six people with all their equipment would have to be flown out from Britain.

The De Beers off-shore operation (Marine Diamonds) offered the use of an underwater camera that could also be lowered to 600 metres below the water surface. After great frustration and many attempts the camera was finally able to provide the following information:- See Figure 15.

a) The pipes were all contained in the bottom 11 metres of the shaft.

b) The visibility in the water was too poor to risk the retrieval of the pipes by the divers.

It was decided to ignore the pipes, leave the ranges that had been lowered where they were (they were much higher off the bottom than was expected) and start again.

5. THE SECOND ATTEMPT

Because the reason for the 'run-away' was still unknown, it was decided to dispense with the use of the rope as a means of lowering the ranges. Diamond drill 'B' rods that could support themselves, plus two attached 25mm ranges over the length envisaged, were to be used. New clamps were also devised to attach the 25mm ranges to the 'B' rods.

5. THE SECOND ATTEMPT continued...

To locate the foot clamps normally used for 'B' rods a platform was designed. It was to be installed above the water level. Ranges were to be attached to the shaft sidewall and to the platform and the 'B' rod ranges would then be lowered to the bottom. The remainder of the operation would be as before, except that the plumbs would be tipped into the water from the platform. A second platform had to be built above the first to permit the rod strings to be assembled before releasing the clamp to lower the ranges.

No problems were experienced, and the ranges were placed in position using the underwater camera to do the final location. See Figure 16 and 17.

Altogether, approximately 4 300 tonnes of plumbs were tipped into the shaft once the ranges were in place. 1 500 Tonnes of cement were used to create the plug using mix of 2 water to 1 cement. This was increased to 1:1 mix in the final stages.

The three pipes (two 25mm and one 'B' rod) were placed so that the 'B' rod was ± 1 metre off the shaft bottom. The first 25mm pipe ended 9 metres above it and the second 25mm pipe ended 9 metres above the first. Grout was injected into all five 'B' rods simultaneously from a surface batching plant and when the level of the rising grout was calculated to have reached the first 25mm range the injection in the 'B' rods was stopped.

Grouting then took place through the first set of 25mm pipes until they too had raised the plug to the level of the start of the second set of 25mm pipes. The final plug was then grouted through these pipes. In actual

5. THE SECOND ATTEMPT continued ...

fact the 'B' ranges and the first 25mm ranges were persevered with until they blocked, before switching to the next set of ranges. To be sure that the plug was effective over its full length, pumping continued even after the top of the plumbs had been covered. See Figure 13.

Once grouting had ceased, a period of twenty-one days was allowed for the plug to cure. In the meantime the stage was brought back to surface and the new 350mm pump column to -300 pump station was installed. The pump chamber was increased in size and the new pumps installed. The larger pumps were an additional precaution in case the plug should leak badly when pumping commenced.

6. PUMPING

Since it was not known to what extent to plug might leak, uncertainty existed as to what size pumps would be required. It was possible that the plug could, in fact, prove a total failure, and to save time, it was decided to utilise the plug curing time to enlarge the -300 pump station and equip it with pumps that would be able to pump down against the incoming water.

Two Sulzer HPH 56-25-4 stage pumps, each capable of pumping 200 litres per second with 1 100kW, 6,6kV motors, were installed. They were connected to a 350mm pipe column which had to be installed from surface to the -300 pump station.

De-watering pumps to be used from or below the stage had to be matched to the Sulzer pumps. They had to be able

6. PUMPING continued ...

to pump at 200 litres per second at a head of 450 metres.

Three alternative methods for installing the de-watering pumps were considered:-

a) To install high-lift centrifugal pumps on the stage and either lower the stage into the water or use submersible pumps suspended below the stage to pump into a suction tank.

   This alternative had a number of major disadvantages:-

   i) Major structural alterations to the stage would have been required to support the pumps, valves and duck's-foot arrangements.

   ii) It would impose severe limitations on the movement of the stage and through the stage if necessary.

b) The second alternative was to build a raft and float the pumps on the water.

   Although this method nullified the disadvantage described under a) it had a major operating defect. The connection from the delivery of the pump to the column would, by necessity, have to be flexible to allow the raft to float downwards as the shaft was de-watered. Although suitable flexible piping could be obtained, it was felt that this method would not permit de-watering of more than a 4,5 metre section at a time.

6. PUMPING continued...

c) The third alternative involved suspending one or more high-lift submersible pumps from a winding rope. This method was selected as it overcame all the disadvantages listed under a) and b). See Figures 18 and 19.

Two Pleuger pumps were selected to match the duty requirement. With both pumps running 200 litres per second could be pumped from a total head of 400 metres. The two pumps were:-

1 x Pleuger P142-9a-VR22 with 650 kW, 6,6 kV motor (two of the nine stages were removed for the initial de-watering down to 600m pump station).

1 x Pleuger Q122-11AV 22-70 with 522 kW, 3,3 kV motor.

De-watering operations started on the 26th September, 1982. The two submersible pumps were supported from one winding rope. Above each pump were 13,5 metres of 150mm diameter pump column; from the ends of these pump columns high pressure flexible hoses (12 metre lengths) connected to a 'trouser-leg' lateral on the end of the pump column.

With this arrangement, about 22 meters of shaft could be de-watered at a time, after which the pump column was extended by two pipe lengths (18 metres) and the process repeated.

Initial problems were experienced with bursting flexible hoses caused by the water falling back down the column when the submersible pumps were switched off. This

6. PUMPING continued...

problem was solved by putting a non-return valve just above the lateral.

The extension of the pump column was difficult. The columns (9 metres long) were lowered through the stage and then pulled up the side with air chain blocks. However, the stage crew soon became adept at extending the column and on several occasions de-watered more than 50 metres of the shaft in twenty-four hours.

The shaft was de-watered to -647 metres below collar on 1st November, 1982. Tests were done to verify that the plug was not leaking and it was decided not to enlarge the -600 metre pump station but to re-install the Salweir MPB 5 pumps that had previously been used during sinking and to continue de-watering with the submersible pumping up to the -300 metre pump station.

The Pleuger P142 pump was restored to nine stages to enable it to pump from the top of the plug to the -300 metre pump station. This was done while equipping the -600 metre pump station.

De-watering operations commenced again on the 6th October, 1982, at a slower rate due to the falling performance of the two pumps as the head increased. After a short time, the flexible hoses had to be replaced with solid piping because of the high water pressures. At about -750 metres below collar the Pleuger Q122 became ineffective and was stopped. The other Pleuger pump continued to pump and an average of 36 metres of shaft was de-watered per twenty-four hours. Pumping operations ceased on the 14th October, 1982, at a depth of ± 910 metres below collar. The de-watering

6. PUMPING continued...

of the final 25 metres of the shaft was achieved by bailing operations.

7. TIGHTENING OF THE PLUG

Prior to drilling from the top of the plug 2 holes were drilled from the -900 pump station. They were intended to intersect the possible 'fissure' in the hope of providing some degree of protection for the crews that were to drill off the top of the plug. These holes never intersected any large amounts of water and were sealed with 8 000kg of cement. See Figure 20.

A total of fifty-four diamond drill holes were drilled from the plug to seal the area before the plug could be removed. These intersected a total of 80 litres of water per second. To seal these holes 1 060 000kg of cement or 1 000 tonnes of grout were used. See Tabulations 12.1, 12.2 and 12.3.

Figures 21 and 22 indicates the successive series of holes that were drilled from firstly, the top of the plug, then the middle of the plug after only 16 metres of it remained and finally from the shaft bottom once the plug had been removed.

8. SHAFT REPAIRS

Once the shaft plug had been successfully removed the stage was once again moved to the surface and the shaft columns were repaired. The clusters of ranges that were left in some of the air and concrete ranges had to be removed.

9. SINKING AND COVER DRILLING

On the 1st March, 1983, almost eight months after having flooded, shaft sinking recommenced, not without problems.

The misfired rounds left in the shaft bottom proved troublesome. Despite advice that the explosives would be inert as a result of the heat of hydration from the cement in the plug, they were found fully intact and 'alive'.

We were fortunate in that having obtained permission from the Government Mining Engineer to drill through the un-examined shaft bottom the penultimate round ended centimetres above the shaft floor. The barring operations exposed the first misfire. Thereafter 55 misfires were located and re-blasted.

10. POST-MORTEM

10.1 De-watered Compartment

No.1 Shaft is located in the "de-watered" Oberholzer compartment of the West Wits line but, since it is positioned between two impervious dykes, it can be considered to be located in a separate sub-compartment. See Figure 1. Bounded on the east by the Bank dyke and on the north-west by the Wuddles dyke, both being intrusive and correlated with the Pilanesberg eruptive event, it is safe to assume that they form a separate compartment unaffected by current mining at depth.

The static water table seen in borehole UD33

10.1 De-watered Compartment continued ...

correlates with the water level established at the time of the flooding and subsequently by the geologist's examination of the exposed fault in the Main Shaft. It can therefore be concluded that any de-watering cones established at existing shafts by pumping operations have no effect on this triangular sub-compartment. This sub-compartment is being replenished, via the regional catchment area overlain by a semi-artesian basin skirting the Loskop to the south-west of Fochville. See Figure 2.

A strike fault located some 2km north-west of No.1 Shaft serves as an important feeder. In addition, several geological discontinuities such as faulting and diabase sills within the Pretoria sediments serve as intraformational water distributing agents.

All these discontinuities within the geohydrological regime and which form part of an interconnecting network will contribute to the water contained in fractures within the underlying dolomite. The major direct feeders are post-Transvaal faults passing transversely through the Malmani dolomite and the overlying Pretoria Group. Re-distribution of water within the dolomite is largely facilitated by fracturing, such as techtonic brecciation and jointing.

An investigation done by a firm of Geotechnical and Structural Consulting Engineers provided the above-mentioned facts and further suggests that a borehole (UD30) drilled in 1977 may have provided

10.1 De-watered Compartment continued ...

a conduit between perched aquifers in the Pretoria series and the dolomite aquifer. UD30 was plugged at 1 140 metres below collar at a position close to the Main Shaft and could have been a primary source of water to the sub-compartment.

Jointing in the dolomite is not closely spaced and is rarely cemented by secondary calcite. The open joints offer a liberal interconnecting network in several directions as indicated by the rosette in Figure 3. This explains the rather haphazard intersection of water in the shaft cover drilling with a tendency to favour the principle north-south joint direction.

10.2 Pre-cementation and Cover Drilling

The pre-cementation rigs were mounted 35 metres from the centre of each shaft to permit headgear foundation excavations to be done concurrently with drilling operations. The intention was to spiral the holes in a clockwise direction round the shaft for maximum cover. In practice this was not achieved, as illustrated in Figure 4.

The geological sequence for the shafts is as follows:- See Figure 5.

Shale, arkose and decomposed arkose to 25 metre below surface

Quartzite and shales with quartzite lenses

Diabase intrusive

10.2 Pre-cementation and Cover Drilling continued ...

Quartzites

Black carbonaceous shales

Diabase intrusive

Interbedded shales and quartzites

Giant chert breccia with base of the Pretoria Group at ± 516 metres BS

Chuniespoort Group dolomites to ± 1 727 metres BS

Black Reef quartzites to ± 1 797 metres BS

Ventersdorp lavas.

Early site investigations had identified a near-surface water problem and therefore no attempt was made from the surface holes to control this water. A separate programme was initiated for this zone. NX casing was grouted in at -378 metres for PC1 and -372 metres for PC2. Pressure tests above this point have shown the holes to be tight in the quartzites, shales and diabase intrusives. A grout curtain was installed before excavation for the foundations began.

This, however, proved ineffectual, as substantial quantities of water were encountered in the excavation, particularly in the weathered arkose. A number of methods were employed to reduce the inflow to acceptable limits including the use of polyurethane foams. Monitoring of a central well

10.2 Pre-cementation and Cover Drilling continued ...

would have shown up the inadequate protection yielded by the grout curtain attempt, but this was, unfortunately, not done.

During shaft sinking, the Main Shaft had only minor water intersections before intersecting the Giant Chert Breccia. The Service Shaft, however, had a number of small intersections, the largest being some 25 650ℓ/hr and which required 31 000kg of cement to seal. It must be assumed that this water was carried on a restricted set of joints which were not intersected by the PC holes.

As the PC holes passed through the Giant Chert Breccia, where substantial water gains or losses might have been anticipated, the variable nature of such aquifers was noted. The Main Shaft and its PC hole passed through virtually dry, while the Service Shaft-PC hole injected some 99 000kg of cement. The injections were, however, successful as the shaft passed through without mishap.

Once the dolomites were intersected, a number of water losses were recorded in both PC holes. In some zones it could be seen that the PC holes had noticeably reduced the amount of cement pumped from shaft cover operations. In others, despite substantial injections in the PC holes of up to 162 tonnes, no real reduction could be seen in shaft bottom quantities.

Both PC holes were lost as a result of rod breakages; PC2 at 1 368 metres and PC1 at

10.2 Pre-cementation and Cover Drilling continued ...

1 055 metres below collar. Despite fishing attempts the boreholes could not be cleared. The Service Shaft was by this time approaching the base of the BX casing. It was therefore decided to abandon the PC holes and to maintain full cover from shaft bottom. PC2 had taken 674 tonnes and PC1 had taken 814 tonnes of cement when they were abandoned. See Figure 6.

After the flooding and de-watering, a plug was cast in the shaft bottom and during the tightening of the plug some 1 145 tonnes of cement were injected to seal the fissure system that had caused the flooding.

i) *Nature of the Fault.* Subsequently, the fissure was exposed in the shaft bottom once sinking resumed. The fault was almost vertical, dipping at 85° to the north-east, striking north-west-south-east. It had only a 400mm downthrow to the north-east and a horizontal displacement of 1 750mm. A 400mm fault zone comprised of 20% breccia and 80% calcite was developed around the fault.

   Jointing in the area had developed prior to the formation of the fault and remained unaffected by the fault. The fault was partially open along its centre-line and examination of over 100 metres of it, which was exposed in the Main Shaft, showed that less than 50% of the fault was open, varying from 0 to 300mm. The water-table in the fault was noted at 450 metres below surface.

ii) *Failure of Detection Methods.* Considering the relative positions of the shafts and the fault with its near vertical dip and the fact that it almost certainly truncated at the base of the diabase some 450 metres below surface, it is most unlikely that the single pre-cementation hole from surface would have intersected it.

The use of several surface pre-cementation holes would not have greatly improved the chances of intersecting this fault.

iii) *The Cover Round.* During the pre-flood sinking, a standard eight-hole cover round was drilled from the shaft bottom using hand held machines. The holes were 48 metres in length and were drilled out at 10° spin. Rounds overlapped by 3 metres and grouting was done using pumps from the shaft bottom.

Subsequent tests using a down-the-hole camera have indicated that major deflections took place in the fracture zone immediately around the excavation. Once in solid un-fractured rock the holes tended to remain in the direction in which they found themselves, as illustrated in Figure 7.

Considering the vertical nature of the fissure and the amount of deflection of the cover holes, it is understandable that they failed to detect the fault.

The sixteen holes drilled at 15° out with

10.3 Precautions to Prevent Reoccurrence continued ...

better to be safe than sorry. The existing cover round takes ± 48 hours to complete in the dolomites and ± 72 hours in the lavas, if no water is intersected. Should water be intersected all drilling ceases and cementation takes place. During the worst portion of sinking after the flooding, cover drilling and cementation took 60% of the available time and it was not uncommon to inject up to ± 700 tonnes of cement per round with a 4:1 water to cement ratio.

11. CONCLUSION

It must be concluded that although surface pre-cementation holes can serve a useful purpose in shallow shafts if drilled in sufficient numbers, their effectiveness in deep shafts must be questioned.

Undoubtedly, they provide advance geological information and must assist in reducing the time that will be spent cementating during shaft sinking. Their lack of cost effectiveness in deep shafts where only one or, at the most, two can be afforded, and the uncertainty whether they have, in fact, sealed all sources of water, must leave Managers in doubt as to their real worth.

Effective sealing of fissures can be assured with good shaft bottom cover drilling. The cost of lost time in sinking is offset against the high capital cost of pre-cementation holes of sufficient number to ensure success.

Cognisance must also be taken of the deflections that occur in cover drilling and an effective surface batch

11. CONCLUSION continued ...

plant operation is essential.

We have learnt, albeit too late, that a de-watered compartment does not mean there is no water to be intersected. This is a geological term that is somewhat misleading to the layman.

12. **TABULATIONS**

DIAMOND DRILL HOLES AND PERCUSSION HOLES DRILLED TO TIGHTEN THE PLUG AND PROVIDE COVER FOR RE-START UP OF SINKING OPERATIONS

		CEMENT kg	SODIUM SILICATE ℓ	Ca CHLORIDE kg
1.	-900 Pump Station			
	2 Diamond drill holes -70° & -80° - 120m deep	175 106	6 460	1 130
2.	-931,5 B.C. - GFC Plug Tightening			
	D/d holes - 15 flat holes 15m deep	314 559	3 060	1 950
	D/d holes - 14 -40° holes 21m deep	436 487	2 176	675
	D/d holes - 21 -80° holes 51m deep	220 094	5 025	1 570
	- 1 vertical hole 51m deep through plug			
3.	Cover Drill No.30 - -953 B.C.			
	Percussion holes:			
	9 horizontal holes 15m deep	88 230	2 730	775
	8 holes -55° dip 30m deep			
	8 holes -40° dip 16m deep			
	16 holes -70° dip 48m deep			
4.	Cover Drill No.30B - -967 B.C.			
	4 flat holes 10m deep West 3 -20° holes West	7 200	-	-
5.	Cover Drill No.31 - -972 B.C.			
	4 d/d holes 120m deep 180°			
	8 percussion holes +20° 30m deep			
	10 percussion holes horizontal 30m deep	243 935	4 620	1 105
	8 percussion holes -40°			
	16 percussion holes -70°			
	GRAND TOTAL: 101 holes	1 241 676kg 1 242 tonnes		

Tabulation 12.1

WATER AND CEMENT GROUTED FROM PLUG - SERVICE SHAFT

HOLE NO.	TOTAL WATER PER HOLE ℓ/hr	TOTAL WATER PER SERIES ℓ/hr	TOTAL CEMENT PER HOLE kg	TOTAL CEMENT PER SERIES kg
VS 1	49 090		83 625	
VS 2	43 100	92 190	15 073	
B 1	170		59 725	
B 2	300		1 130	
B 3	340		2 300	
B 4	50		300	
B 5	400		580	
B 6	500		2 990	
B 7	76 050		238 349	
B 8	150		1 600	
B 9	200		175	
B 10	550		1 535	
B 11	16 450		3 890	
B 12	29 820		1 860	
B 13	0		120	
B 14	0		120	
B 15	0		120	314 914
B 16	0	124 980	120	209,82cu.m.
C 1	0		360	
C 2	0		350	
C 3	0		220	
C 4	0		1 220	
C 5	6 000		1 535	
C 6	1 800		194 800	
C 7	2 000		730	
C 8	0		23 830	
C 9	0		156 732	
C 10	0		280	
C 11	9 000		3 650	
C 12	1 980		3 250	
C 13	11		5 000	435 937
C 14	12 [illegible]	43 780	43 980	290,62cu.m

Tabulation 12.2

WATER AND CEMENT GROUTED continued ...

HOLE NO.	TOTAL WATER PER HOLE ℓ/hr	TOTAL WATER PER SERIES ℓ/hr	TOTAL CEMENT PER HOLE kg	TOTAL CEMENT PER SERIES kg
1	3 600		5 720	
2	12 600		5 565	
3	0		7 650	
4	0		6 750	
5	50		7 525	
6	0		6 960	
7	0		4 520	
8	0		6 780	
9	0		9 035	
10	0		9 134	
11	0		4 975	
12	0		4 335	
13	0		7 300	
14	50		2 650	
15	0		2 580	
16	400		6 105	
17	9 000		17 116	
18	2 400		5 755	
19	3 900		10 000	
20	2 200	34 200	22 710	153 215 102,14cu.m.
18A	1 800	1 800	2 330	2 330 1,55cu.m.
B Rod	500	500	49 830	49 830 33,22cu.m.
Centre	900	900	5 400	5 400 3,60cu.m.
TOTAL	**298 350**		**1 060 324**	**706,88cu.m.**

Tabulation 12.2

ADDITIONAL DATA SERVICE SHAFT FLOODING

1. TOTAL AMOUNT OF WATER PUMPED OUT

Time taken = 15 days

Volume = 48 027cu.m.
= 48 027 873ℓ

Pumping rate = 133 410ℓ/hr
or 37ℓ/s

Includes leakage = 5ℓ/s

2. TOTAL AMOUNT OF CEMENT USED UP TO TIGHTENING OF PLUG

a) Casting plug = 2 185 340kg (2 185t) and 1 457cu.m.

b) Grouted dry cement = 1 060 324kg (1 060t) and 707cu.m.

After tightening Plug

c) Mid-plug cementation = 98 230kg (98t) and 65cu.m.

d) Shaft bottom = 243 935kg (244t) and 163cu.m.

3. TOTAL TIME FROM START TO FINISH

9th July, 1982 until 28th February, 1983 inclusive.
235 days (one week short of eight months).

Tabulation 12.3

13. CHRONOLOGICAL ORDER OF MAIN EVENTS

09.07.1982 - Initial outbreak occurred

10.07.1982 - Decision taken to flood and withdraw stage

14.07.1982 - Water levelled at -418 metres below collar

17.07.1982 - -300 Pump station enlarged

19.07.1982 - -300 Pump station supported

20.07.1982 - First range lowered into shaft

21.07.1982 - Second range lowered into shaft

22.07.1982 - Third range ran-away

13.08.1982 - Underwater camera scans completed

16.08.1982 - Platform constructed above water

23.08.1982 - Cementation ranges on sidewall to platforms

26.08.1982 - Commenced tipping plumbs from platform

29.08.1982 - Completed tipping of 4300 tonnes of plumbs

30.08.1982 - Upper platform constructed

03.09.1982 - Ranges complete to shaft bottom (camera checked)

- Grout injections of plug commenced

07.09.1982 - Injections complete

08.09.1982 - 350mm Pump column, cables etc to -300

23.09.1982 - Pump chamber commissioned

26.09.1982 - Started de-watering to -600 pump station

06.10.1982 - -600 Pump station commissioned

14.10.1982 - Shaft de-watered to top of plug

16.10.1992 - Started drilling from -900 pump station

13. CHRONOLOGICAL ORDER OF MAIN EVENTS continued ...

01.11.1982 - Cementation from -900 complete

28.12.1982 - Plug tightened after cementation of 54 diamond drill holes

13.01.1983 - Shaft repairs completed and lashing unit recommissioned after overhaul

14.01.1983 - 2 Metres of the plug removed by blasting

20.01.1983 - 20 Metres of plug removed to date and reclaimed old tubing plates

23.01.1983 - Cover drilling commenced from the middle of the original plug

06.02.1983 - Completed mid-plug tightening. 98 Tonnes of cement injected

07.02.1983 - Started blasting of remaining plug

13.02.1983 - Last portion of plug blasted out

14.02.1983 - Moiled out final plug

- 55 Misfires located and blasted

- 2 Metres blasted into virgin ground

15.02.1983 - Commenced shaft bottom cover drilling

28.02.1983 - All cover holes and diamond drill holes sealed

Progressive injection:

- 243 935kg cement
- 1 105kg calcium chloride
- 4 620 litres sodium silicate

01.03.1983 - Service Shaft back to full sinking operations

14. ACKNOWLEDGEMENTS

The author wishes to thank the Consulting Engineer, Anglo American Corporation, West Rand Region, for permission to publish this paper.

Assistance is also acknowledged from the following: Gold Fields Cementation Company, Webb & Partners (Consulting Civil, Geotechnical and Structural Engineers), Geology Department (Anglo American Corporation of S.A., Ltd), and Members of the Western Deep Levels (South) Project Team.

Introductory Remarks by the Author. The author does not consider himself either an expert on flooding or a professional speaker, but he felt it necessary to present this paper for the following reasons.

At the time of the flooding there were no experienced staff to tackle the problem, and very few documented precedents could be found.

Shafts had flooded in the past and had been recovered, for example, Blyvooruitzicht in 1937 and Free State Geduld in 1954. No documentation was available with regard to these similar incidents, and although it is hoped that no Manager in the future will need the information, the author decided to record the incident at Western Deep Levels and to describe how the recovery of No.1 Shaft was conducted.

Gratitude must be expressed to all those people and organisations which came to our assistance, especially Gold Fields Cementation Mining Company. Mr Garret, retired Chief Executive of that Company, a man with vast experience in the West Wits area, was of invaluable assistance to us. Yet even he, in the end, said, "It is easy to give advice and

14. ACKNOWLEDGEMENTS continued ...

recommendations, but in the end it is the Manager's responsibility to decide what must be done."

Some attempt is also made in this paper to explain the probable causes of the flooding and to give an account of the precautions that have been taken to prevent a recurrence.

The author hopes that by publishing this paper he may offer to other Managers the experience at Western Deep Levels, and that they will take the precautions prescribed therein.

Contributed Remarks by M. H. Carlisle. The subject of plugs and bulkheads has, over the years, been well documented by the mining industry in this country.[1] However, very little information is available regarding underwater plugs. The author is therefore to be congratulated and thanked for his presentation on this subject to the Association, as it is considered important to provide some detail as to the actual design of the plug and the placement of the grout.

The plug length was initially determined using the standard formula for parallel-sided plugs as laid down by the Chamber of Mines of South Africa.[2] The plug length of 17 metres thus derived was considered adequate but due to some doubts expressed as to pure cement grout mixes, Mine Management decided to increase the plug length to 27 metres. The plug therefore extended into the lined portion of the shaft which meant that is was keyed-in as an added precaution.

As the water break-in point was in the sidewall, it was believed the main thrust on the plug was lateral and not vertically upwards thus reducing the possibility of 'piston effect' on the structure. This meant a greater degree of safety for personnel working on the plug after de-watering

14. ACKNOWLEDGEMENTS continued ...

After the plug had reached a height of approximately 4 metres above bottom, water was added in the shaft. This effectively induced a reverse flow into the water break-out point. Water was added at regular intervals to maintain a small positive pressure on the inrush point. The reverse flow was started at 0h30 on the 4th September, 1982 and at 14h00 on the same day it was noted that the water in the shaft was rising without water addition indicating that the opening had closed off. At that time, ranges which were not in use were being water tested at thirty-minute intervals. One range which was clear at 13h30 was found to be blocked shortly after 14h00. It was therefore assumed that the grout had passed the discharge end of the range causing the blockage. Thus the plug height was known. From this information, the volume of grout placed was calculated and compared with the cement grout volume pumped. A discrepancy of some 220 tonnes of cement was found, and it was assumed that this cement had been reverse-flowed into the water inrush zone. At best, this calculation can only be re-garded as giving an educated guesstimate and should not be regarded as completely accurate. However, it is certain that there was a substantial flow of grout into the fissure zone and that this played a major part in preventing leakage along the rock/plug interface when the plug was subjected to the full static head.

The grout plant was made up of two separate units. Each unit consisted on the following:

Two 100 tonne cement silos,
One weighbatcher and water measure,
A 1 200 litre primary mixer,
Two Dean shear mixers of 1 000 litre capacity,
Three 500 litre agitator storage tanks,

14. ACKNOWLEDGEMENTS continued ...

but concern was expressed with regard to possible leakage along the plug/rock interface. This was a second good reason for increasing the plug length.

Initially, it was decided to pump a cement/water ration of 1 to 1 by mass. However, experimental work on a 1 in 20 scale model of the shaft bottom and a 400 metre long 25mm range on surface proved that a considerably stronger grout was feasible. Nevertheless, a conservative, safe policy was decided on and, when grout pumping began, a 1 to 1 mix was pumped and increased gradually to 2 cement to 1 water while carefully monitoring the pump pressure required. As no problems were evidenced, this mix was continued to the completion of the plug. The average mix was probably of the order of 1,8 to 1 as estimated from the final size of the plug as against the cement used.

Samples of the grout taken during plug removal some seven months after placement gave an average compressive strength of 16,5MPa. The theory of the grout placement method is to introduce grout as close to the shaft bottom as is possible from one range in each bank. The grout then disperses fairly evenly across the shaft. As the grout is denser than the water, it lifts the water above it and very little mixing of the flooding water and grout takes place, except in the top one metre or so. Thus, the fresh grout introduced at the shaft bottom tends to lift the previously placed grout and the water.

This method appeared to have been a complete success. When the plug was removed, the top of the plug consisted of comparatively weak grout (6-10 MPa) and had horizontal planes in it, whereas further down into the plug, the concrete was homogeneous and solid throughout.

Three 500 litre feed tanks, and
Three cementation pumps plus one standby.

All mixers and tanks were hydraulically driven and the pumps were air driven. The only serious problem during the plug pour was caused by the build-up of grout in the various tanks and mixers. In retrospect, two methods of overcoming this problem are evident. The first, which is now available, is an improved impeller design in the mixers and the second is to have a third unit. This would enable the crew to shut down one unit at a time for cleaning and maintenance. As continuous operation is vital to the success of a plug pour, this standby plant should be incorporated in all future designs.

The average rate of throughput was 570 tonnes of grout per twenty-four hours with a best performance of 610 tonnes. During this latter period, six pumps were in operation as compared to four or five during most of the 92 hours of pumping. This involved a total cement delivery of 2 185 tonnes or 90 tankers. During one period of 12 hours, 14 tankers were discharged. Tanker discharge time was thirty to forty minutes. As it was vital to maintain a continuous pour, the organisation between cement suppliers, Mine Management and Stores personnel and Contractor had to be and was very good throughout.

REFERENCES

1. Lancaster, F.A. Report on Research into Underground Plugs. *Transvaal and Orange Free State Chamber of Mines - C.O.M. reference: Project No. 203/64/- Research Report No.27/64, August 1964.*

REFERENCES continued ...

2. Construction of Underground Plugs and Bulkhead Door Using Grout Intrusion Concrete. Code of Practice. *Published by the Chamber of Mines of South Africa* - February, 1983. *(N.B. This publication was available in draft form at the time of the water inrush. In addition, a previous Code of Practice was available.)*

ooOOOoo

FIGURE 1

WESTERN DEEP LEVELS LIMITED
LOCALITY MAP

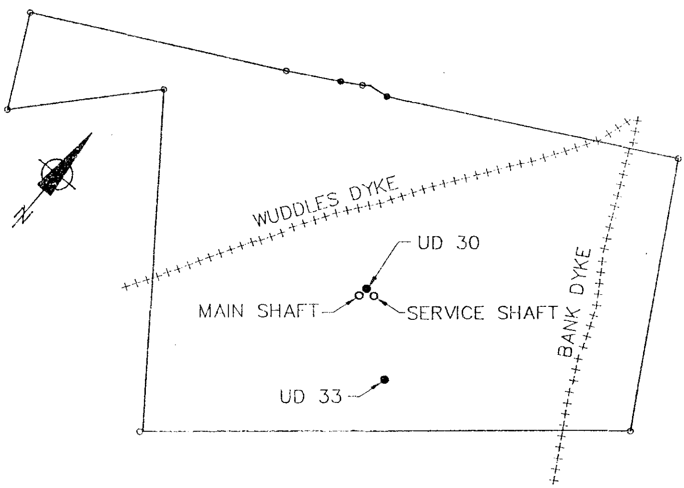


FIGURE 2

WESTERN DEEP LEVELS LIMITED
LOCALITY MAP

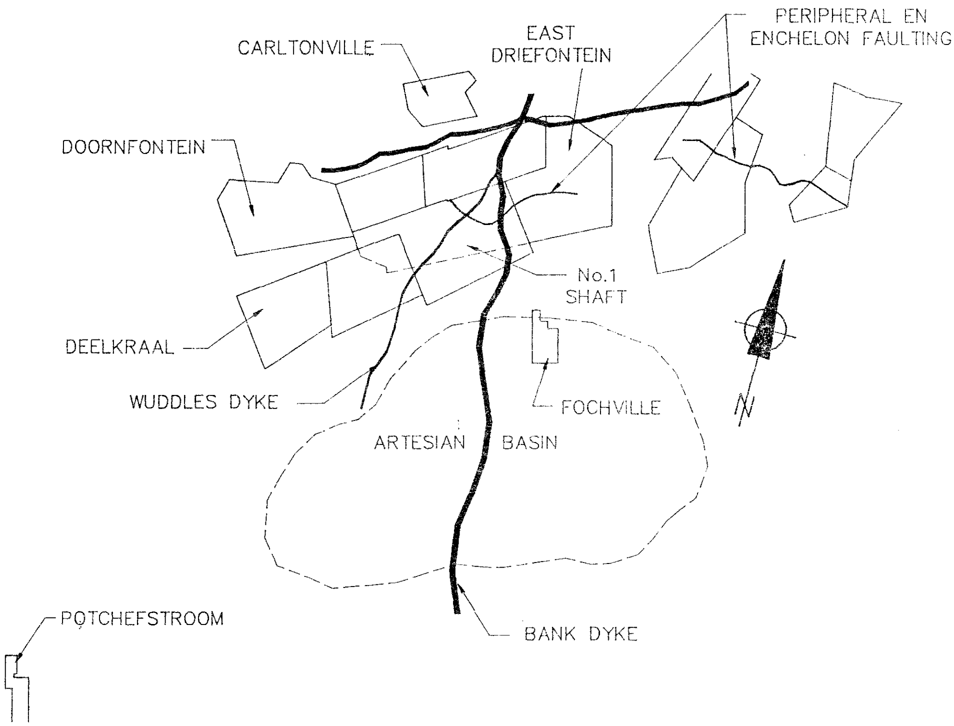


FIGURE 3

WESTERN DEEP LEVELS LIMITED
JOINTING ROSSETTE

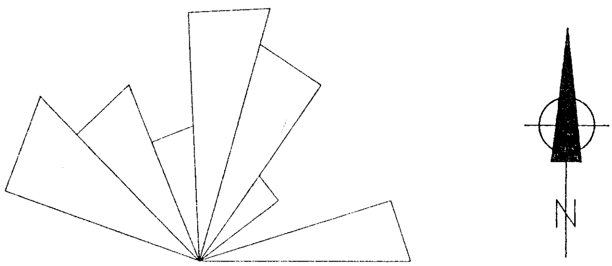


FIGURE 4

WESTERN DEEP LEVELS LIMITED

PLAN SHOWING SHAFTS AND PC1 AND 2 BORE HOLES

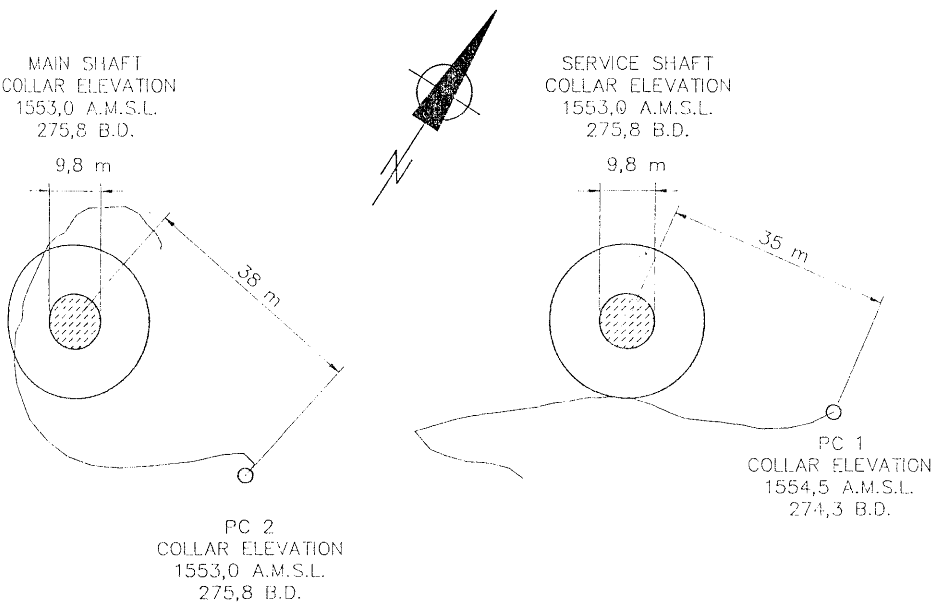


FIGURE 5

WESTERN DEEP LEVELS LIMITED
ELEVATION SHOWING SHAFTS AND PC1 AND 2 BORE HOLES

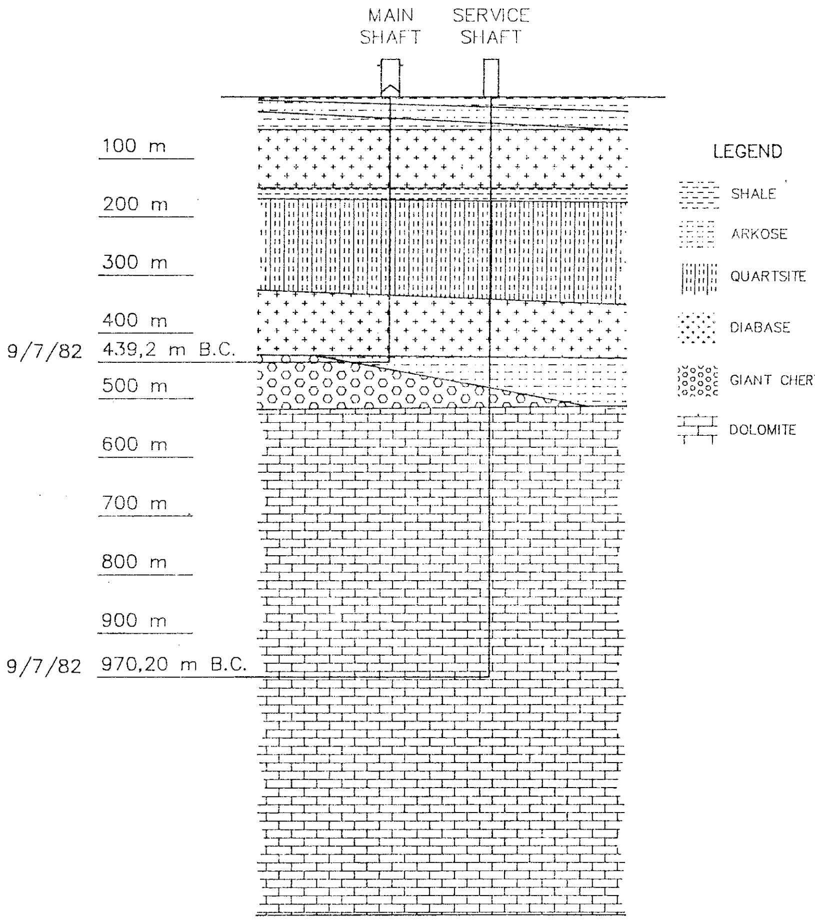
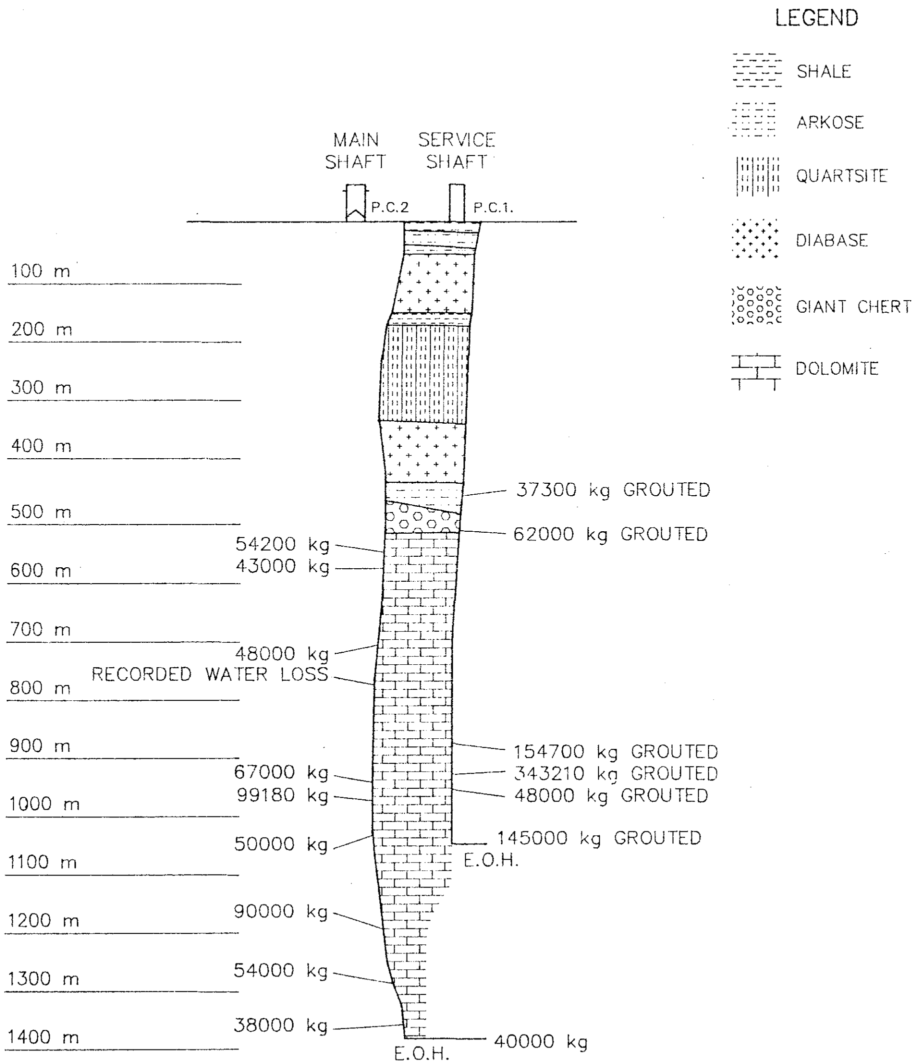


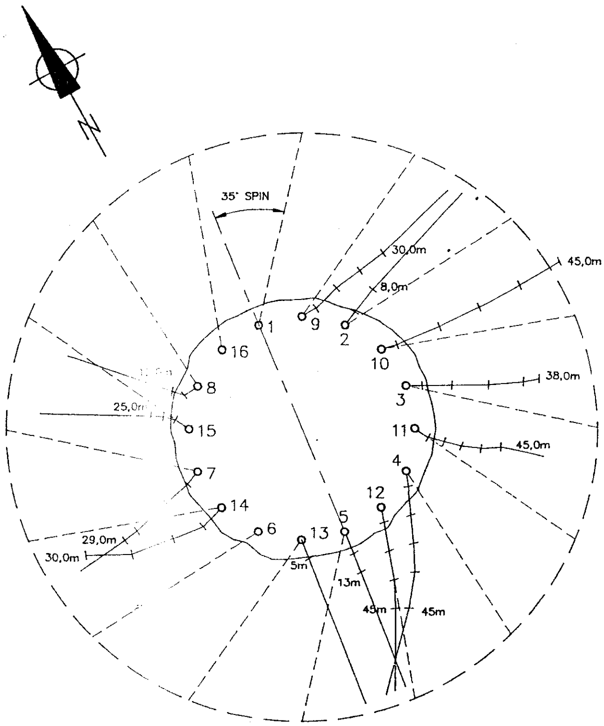
FIGURE 6

WESTERN DEEP LEVELS LIMITED
ELEVATION SHOWING SHAFTS AND PC1 AND 2 BORE HOLES



-IGURE 7

No.1 MAIN SHAFT COVER HOLE LAYOUT
(1) DEFLECTIONS BEFORE USE OF RIG



COVER HOLE DATA
REQ. DIP −80°
REQ. DEPTH 48m
REQ. SPIN 35°

SECTIONAL VIEW OF STANDARD COVER ROUND MAIN AND SERVICE SHAFT REV 1

FIGURE 8

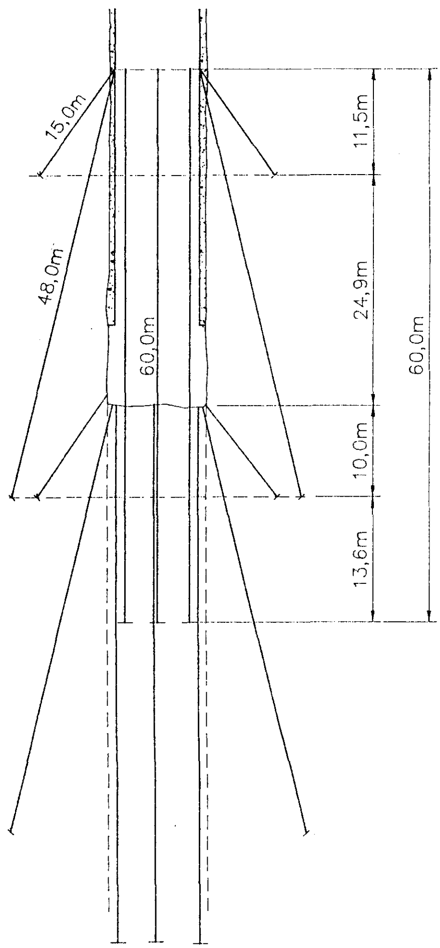
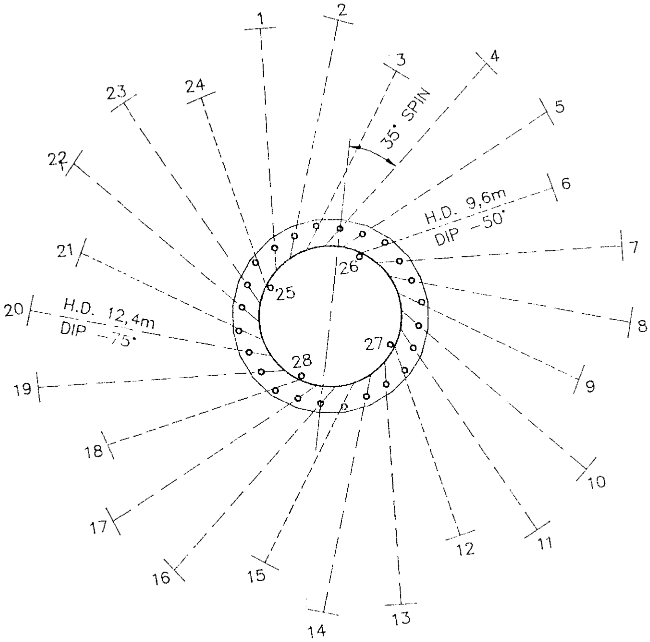


FIGURE 9

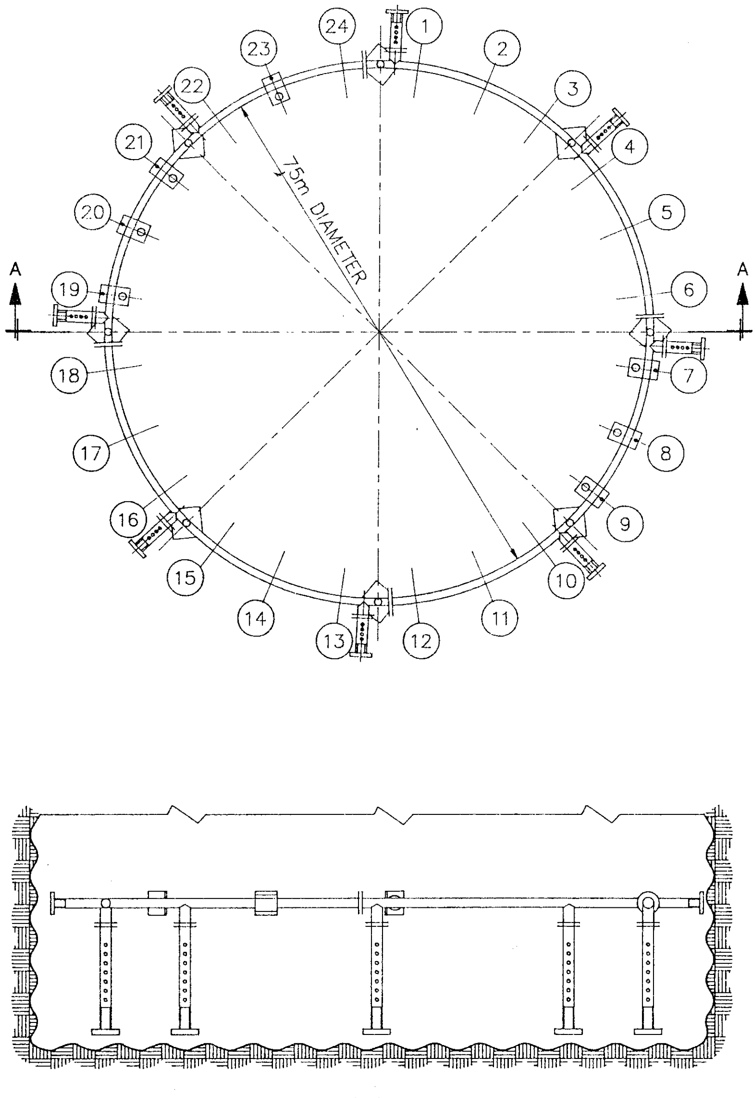
PLAN OF STANDARD COVER ROUND MAIN AND SERVICE SHAFT REV. 1 (F)



35° SPIN ON HOLES 1–24
8 HOLES 15,0m DEEP 40° OUT FROM VERTICAL
16 HOLES 48m DEEP 15° OUT FROM VERTICAL
4 VERTICAL HOLES 60,0m DEEP

FIGURE 10

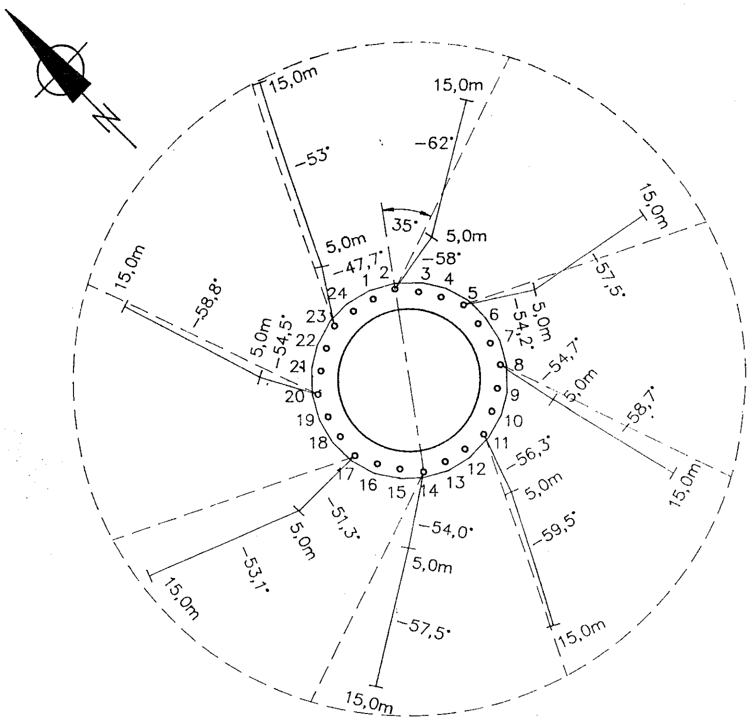
WESTERN DEEP LEVELS LIMITED
PLAN OF DRILL RIG



SECTION A—A

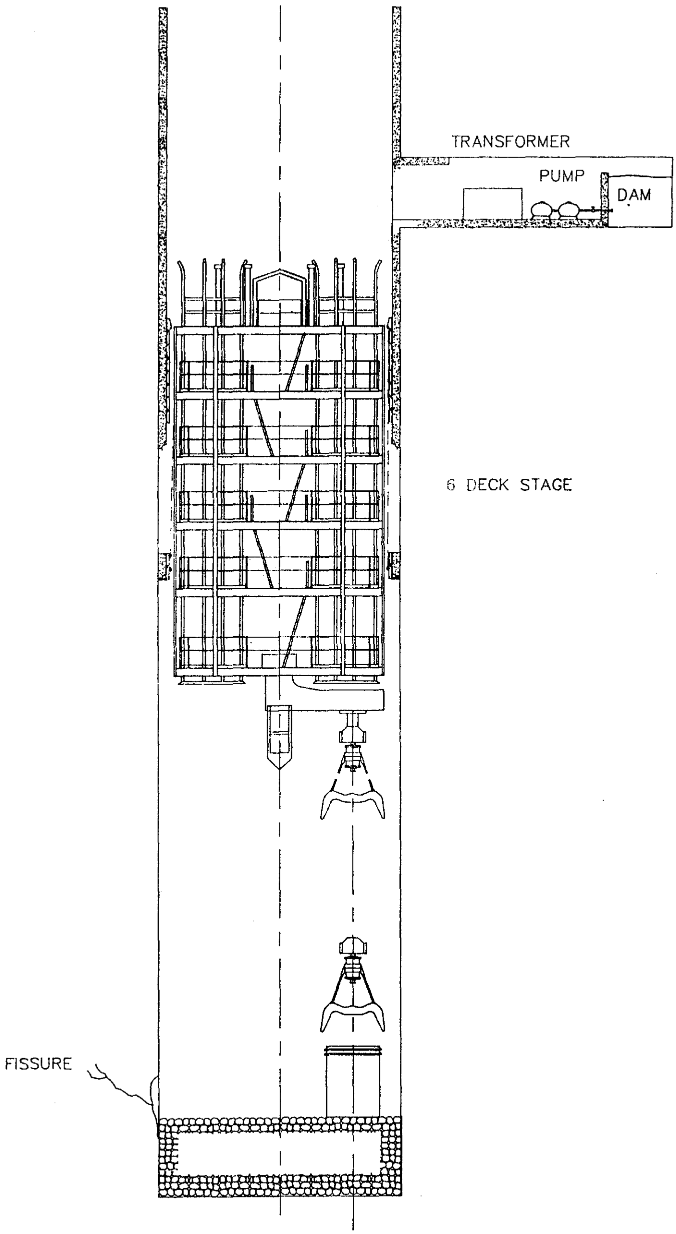
FIGURE 10A

No.1 MAIN SHAFT COVER HOLE LAYOUT (2) DEFLECTIONS OBTAINED USING DRILL RIG



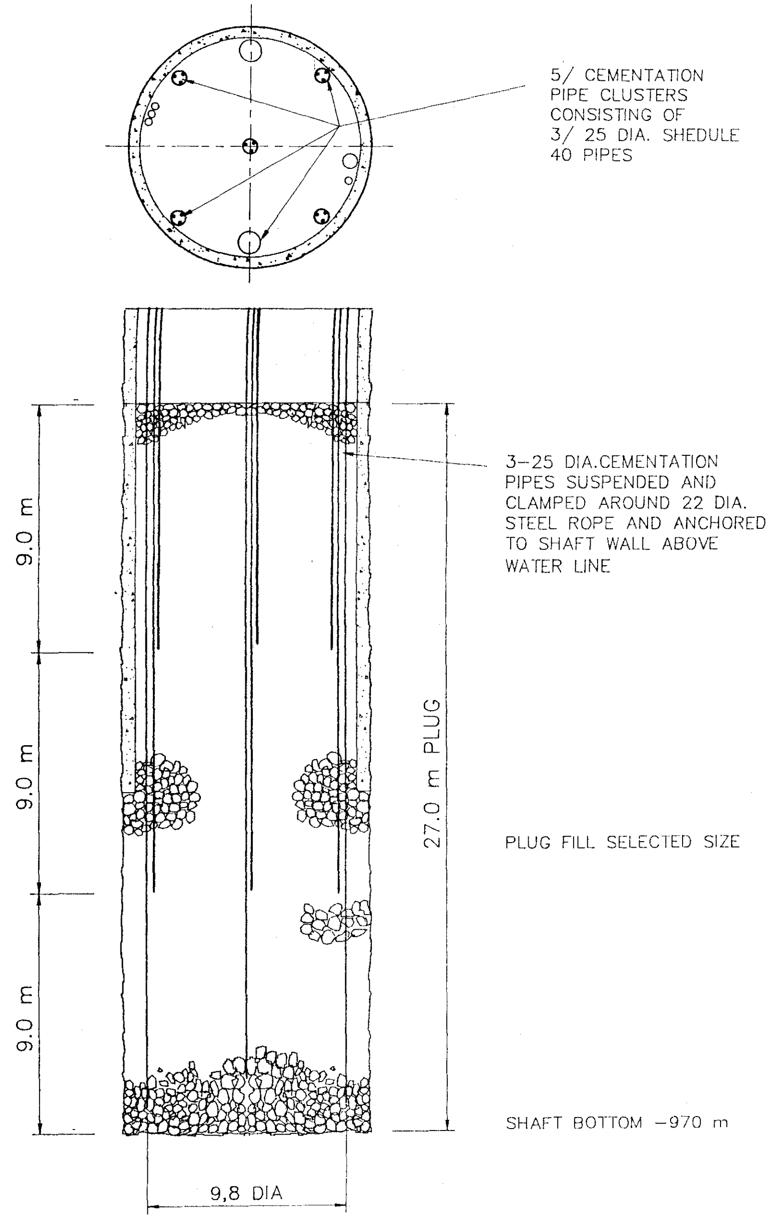
COVER HOLE DATA
REQ. DIP -50°
REQ. DEPTH 15,0m
REQ. SPIN 35°

FIGURE 11



9:30 pm FRIDAY 9th JULY 1982

FIGURE 12



SECTION THROUGH PLUG AS PLANNED

FIGURE 13

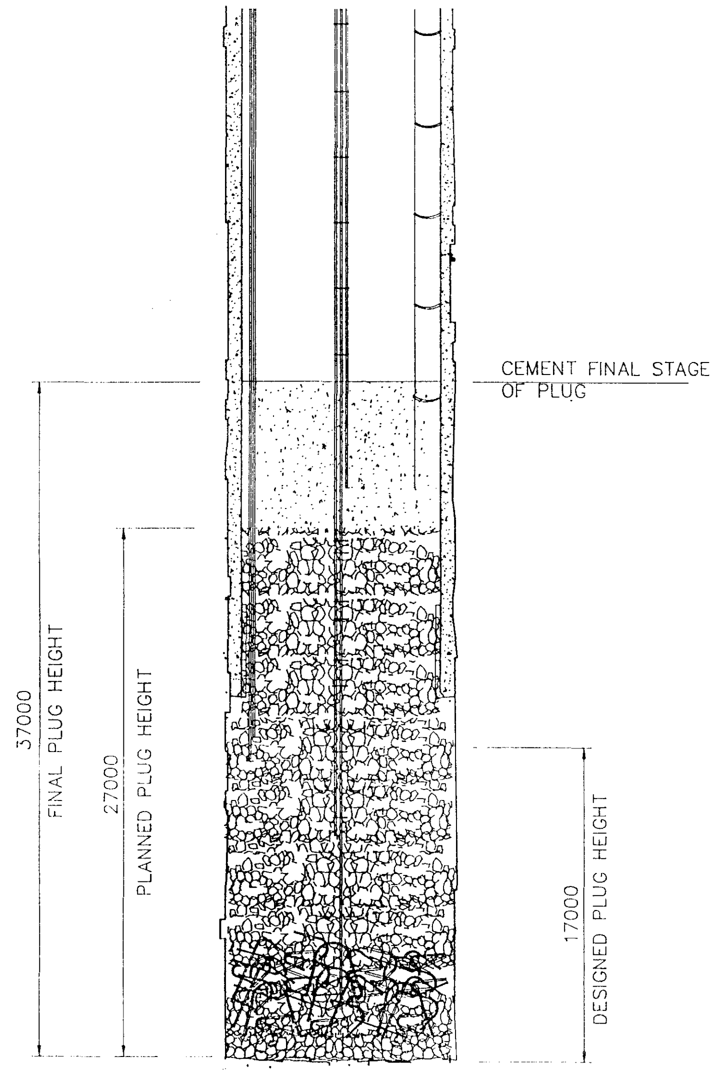

CEMENT FINAL STAGE
OF PLUG
37000
FINAL PLUG HEIGHT
27000
PLANNED PLUG HEIGHT
17000
DESIGNED PLUG HEIGHT

FIGURE 15

CAMERA CAGE AND CENTRE RANGE

B – RANGE

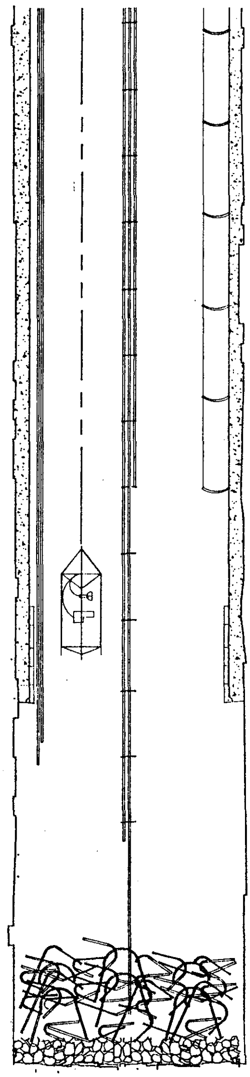
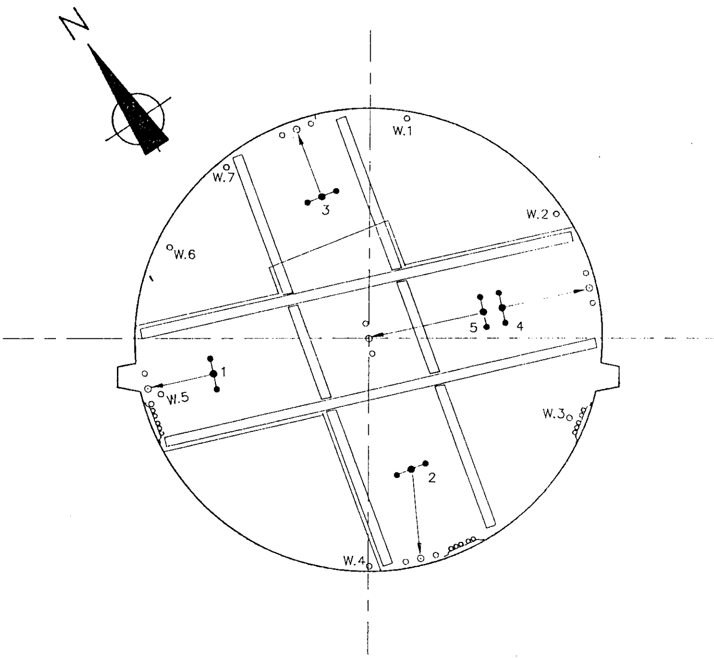


FIGURE 16

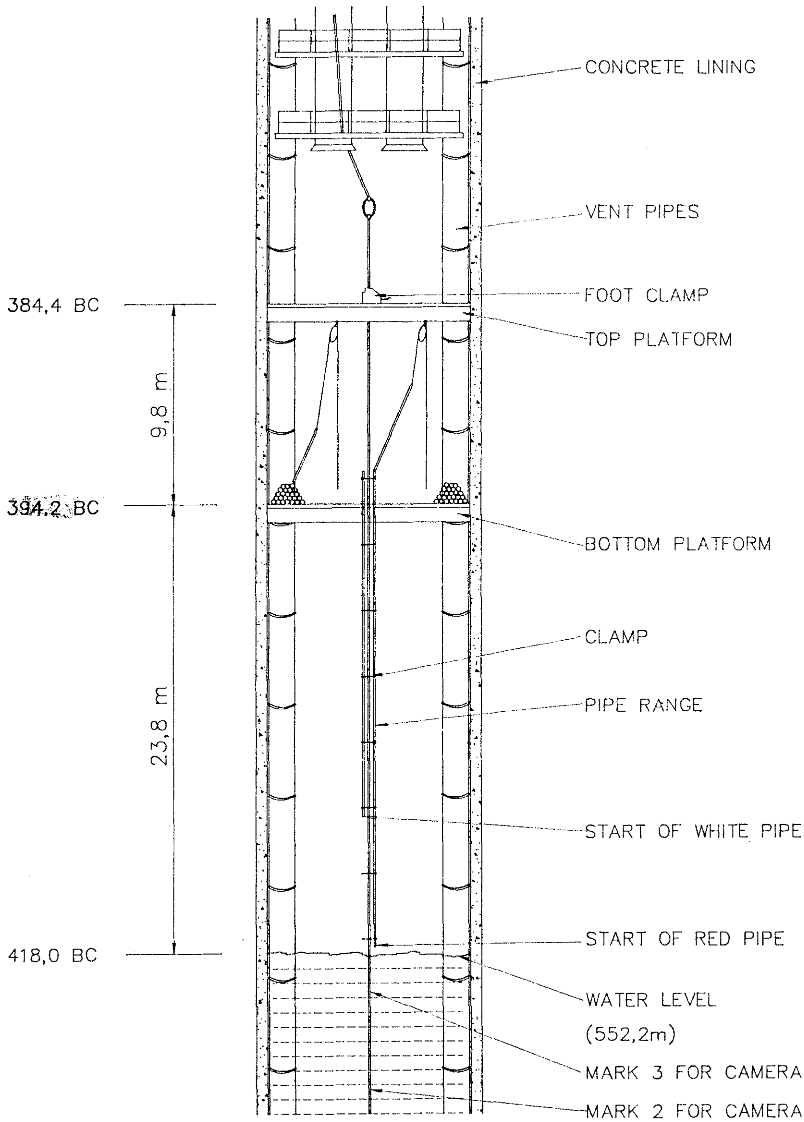
No.1 SERVICE SHAFT
PLAN ON 394 m B.C.



LEGEND

- •–2–• POSITION AND SEQUENCE IN WHICH PIPE COLUMNS WHERE LOWERED
- ○ ○ ○ POSITION IN WHICH PIPE COLUMNS WERE CLAMPED

FIGURE 17



SERVICE SHAFT DEWATERING PLATFORMS

FIGURE 18

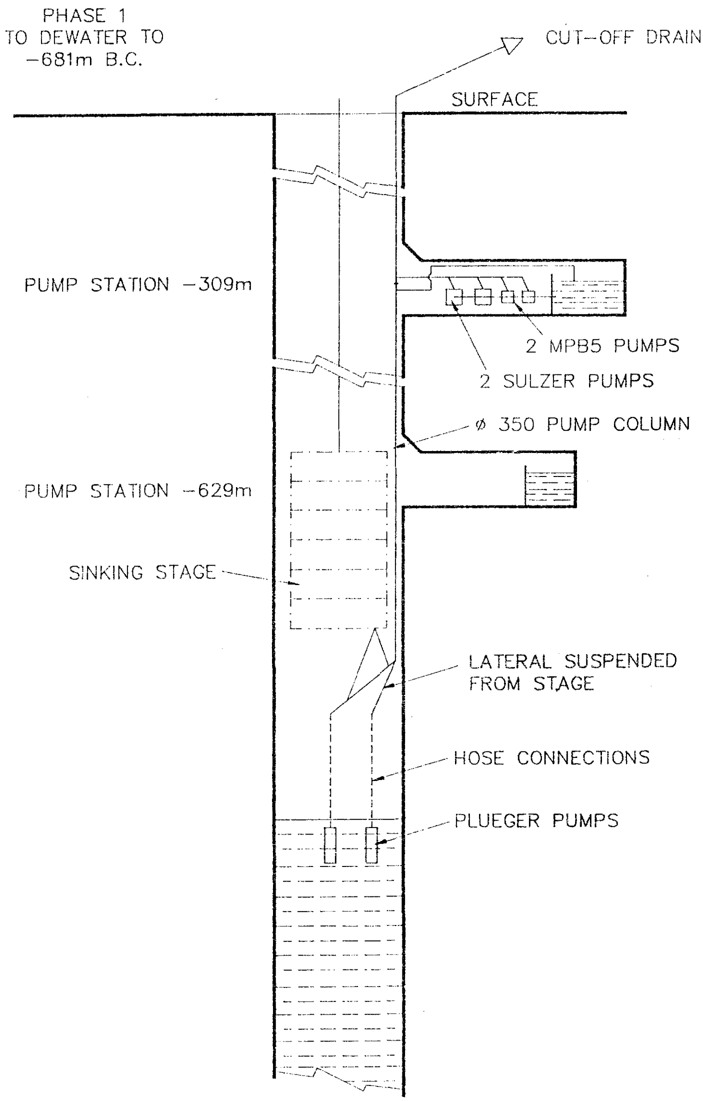

PHASE 1
TO DEWATER TO
−681m B.C.
CUT–OFF DRAIN
SURFACE
PUMP STATION −309m
2 MPB5 PUMPS
2 SULZER PUMPS
ø 350 PUMP COLUMN
PUMP STATION −629m
SINKING STAGE
LATERAL SUSPENDED
FROM STAGE
HOSE CONNECTIONS
PLUEGER PUMPS

FIGURE 19

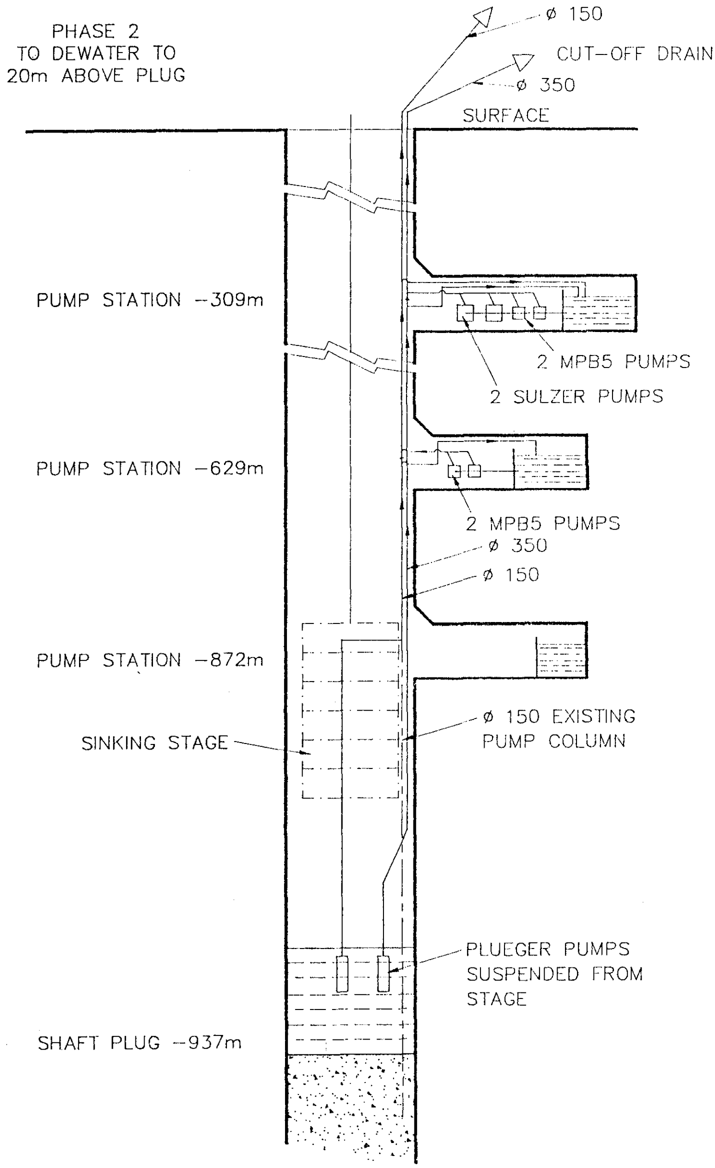

PHASE 2
TO DEWATER TO
20m ABOVE PLUG
ø 150
CUT–OFF DRAIN
ø 350
SURFACE
PUMP STATION –309m
2 MPB5 PUMPS
2 SULZER PUMPS
PUMP STATION –629m
2 MPB5 PUMPS
ø 350
ø 150
PUMP STATION –872m
SINKING STAGE
ø 150 EXISTING
PUMP COLUMN
PLUEGER PUMPS
SUSPENDED FROM
STAGE
SHAFT PLUG –937m

FIGURE 20

PROPOSED RELATIVE POSITIONS
OF V.S.1 AND V.S.2

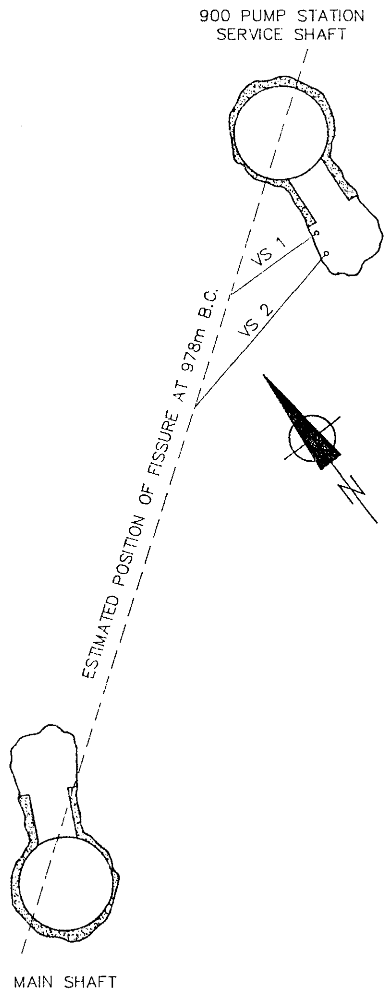


FIGURE 21

PLUG SECURING HOLES SIDE VIEW

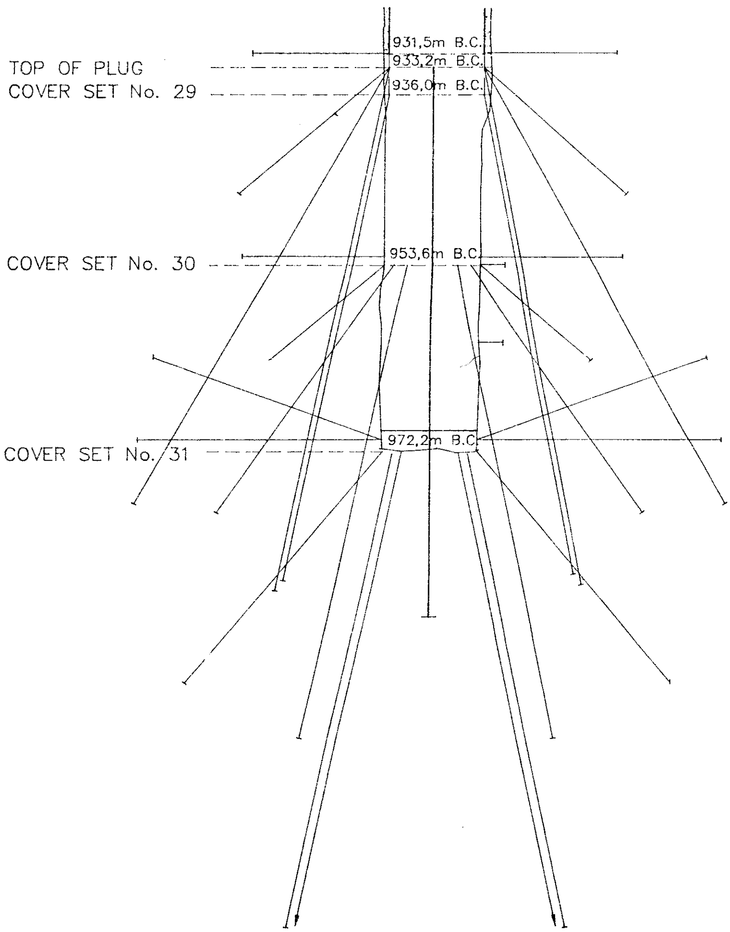
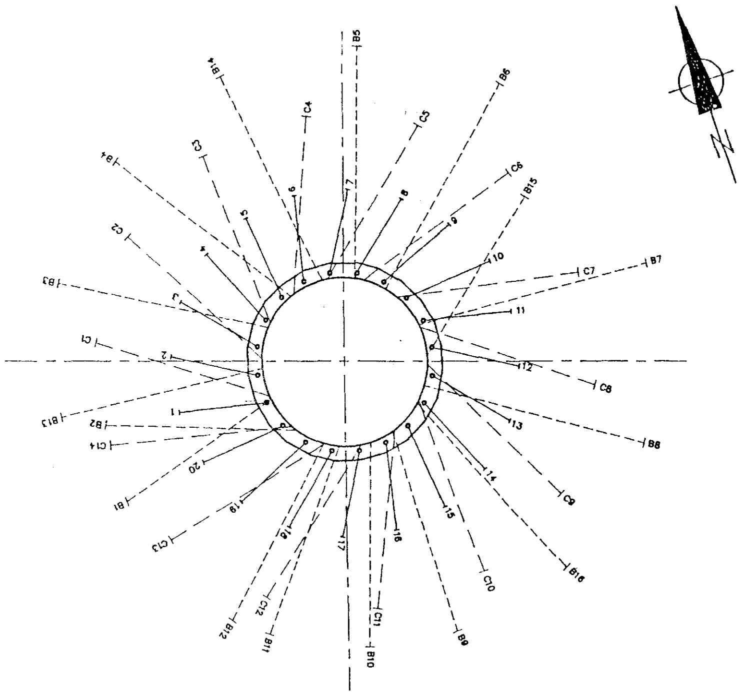


FIGURE 22

PLUG SECURING HOLE LAYOUT IN SERVICE SHAFT AT 933,2 B.C.



HOLE DATA

HOLE SERIES	DIP	DEPTH	SPIN
1,2,3 ETC.	-80°	50,0m	20°
B1,B2 ETC.	FLAT	15,0m	NO SPIN
C1,C2 ETC.	-40°	21,0m	35°

FIGURE 23

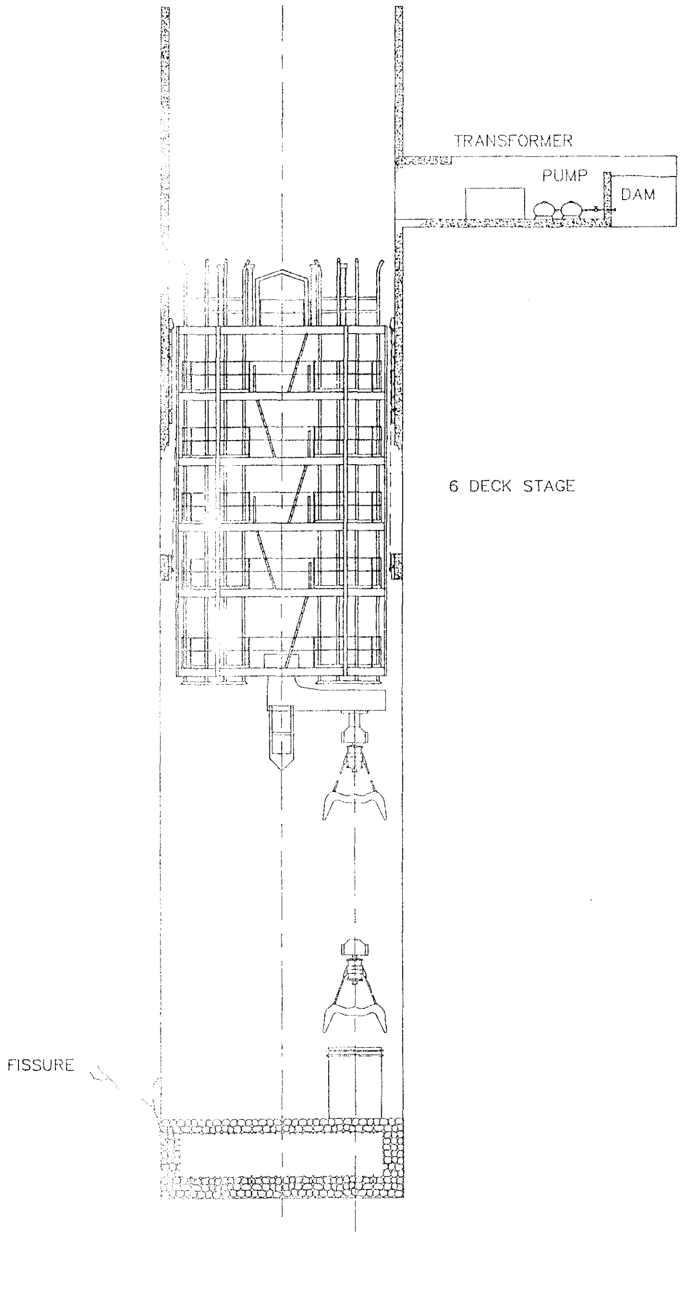


FIGURE 25

WESTERN DEEP LEVELS LOCALITY PLAN