CONSTRUCTION OF A CONCRETE PLUG IN THE SOUTH DEEP'S MAIN SHAFT TO SEAL OFF A MAJOR WATER INTERSECTION

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ABSTRACT

This paper describes the method used to salvage the South Deep's Main Shaft after it was flooded by an inrush of water at about 450 metres below collar on 1 May 1996. The individual techniques employed in the salvage were all proven technology but the combination in which they were applied was novel and we believe unique and so meriting the recording of the operation. It involved the following activities in order of occurrence:-

- The dewatering of the shaft with submersible pumps.
- The placement of a French drain on the shaft bottom muck pile.
- The positioning of large diameter heavy walled draft tubes and smaller tightening up, grout intrusion and reverse flow pipes.
- The casting and curing of a structural concrete plug. The capping of the draft tubes. The intrusion of several thousand tons of cement grout into the aquifer by pressure induced reverse flow.
- The sealing of the aquifer.
- The extensive probe drilling and sealing of the zone around the inrush point with cement and other specialized grouts.
- The mining out of the plug and the re-establishment of normal sinking routines.

INTRODUCTION

South Deep is a twin shaft project. The main and ventilation shafts are being sunk to design depths of 2 765 metres and 2 760 metres respectively, making them the world's deepest single-lift shafts. They have a finished lined diameter of nine metres. The shafts are being sunk at Western Areas Gold Mine for JCI Limited.

The method of sinking, utilises seven boom sinking drill rigs with pneumatic drifters to advance three metre rounds. Cactus grab units are used for mucking into 16 ton kibbles which are hoisted to surface by double drum winders. The hoisting is guided by a crosshead on the stage ropes. A six deck working stage provides access for concrete lining of the shaft. A six metre high shutter is used and a concrete lift is cast per day concurrent with sinking.

The initial cover drilling procedure was a standard ring cover round of eight holes, drilled 48 metres deep, dipping at 10° from the vertical with a 12° clockwise spin. When required, additional umbrella holes were laid out. Typically 24 metre deep, dipping 20° from the horizontal and 20° anti- clockwise spin in problem areas as designated by the Geologist.

Cover overlaps maintained at no less than eight metres. The detailed cover drilling procedure and injection procedures used during the project deserve a separate technical paper.

Some of the more important precautions detailed in the procedures are:-

° Sinking to stop 10 metres short of any known large water intersection above 10 000 litres per hour as determined by previous cover holes. The standard cover round must then be redrilled.

All holes injected to 2½ times static head and plugged with thick grout.

° All holes with more than 100 litres per hour to be redrilled and deepened by three metres.

The shaft is so sited that it traverses the steeply dipping Broken Arrow fault at the intersection point of the giant chert breccia above the Malmani Dolomites of theTransvaal series. (See Figure 1 Shaft Elevations on 1 May 1996).

The shaft bottom was within the standard 8 hole cover lift, drilled from -418m and which included four additional flat holes.

THE WATER INRUSH

On 1 May 1996 a round was drilled at -447m and blasted at 08:30.

On re-entry water was noticed in the blasted rock. It was established that the water intersection was on the sidewall in the North West sector of the shaft on the Broken Arrow Fault. Estimated ingress of ± 10 000 ℓph. Water was bailed by means of kibbles for approximately five hours, then split set support installation from the muck pile was started, while bailing continued for two hours. After a further two hours of bailing, four hours of shotcrete operations followed which were concurrent with bailing.

By midnight the bailing no longer matched the inflow and the bottom flooded. The inflow was now 80 000 ℓph and eventually increased to 165 000 ℓph. The water level was now rising at a rate of two metres per hour. This forced a tactical withdrawal up the shaft.

The concrete kettle and shutter turnbuckles were stripped, the stage raised, concrete, air and ventilation pipes stripped and sent out, while bailing continued. The kibbles were converted into bailers, by cutting holes and installing flaps in their bottoms.

Bailing and stripping of services continued for 2½ days while pumps were being sourced.

Pleuger pumps were located at Freegold's IMS store in Welkom. The sinking cables were inadequate for the power required for pumping so the stage was raised to surface, and then lowered whilst installing HT power cables.

Two bearer sets were installed to support the pump column and services were re-installed. The Pleuger pump was suspended below the ventilation recess in the stage by means of slings and chainblocks. The electrical reticulation was completed and after repairing a damaged gasket on the make up piece, pumping commenced on 6 May at 14:00, two days after raising the stage.

During this time the water level had risen by 138,4 metres to -308,6m below collar. After commissioning the pumps the water level was lowered to -433 metres below collar in five days by bailing and pumping. The pump delivered ± 250 000 ℓph to surface. It took approximately 30 minutes to install a six metre length of pump column during which time the water level would rise by a metre. It therefore meant that the water level had to be lowered by eight metres to install a six metre length of pipe column.

On 11 May 1996 diamond drilling commenced off the stage after the north side kibble hole had been decked off.

Drilling continued for five days while the pump held the water between -433 metres and -439 metres.

On 16 May 1996 a site meeting was held to consider options, and decide on a course of action.

OPTIONS

Drilling

- Drilling from the stage
- Excavate a drilling cubby at -431m

Ex Vent Shaft

- Excavate a pump chamber in the Vent Shaft at -425m and drill a miniborer hole through to -410m in Main Shaft
- Sink Vent. Shaft to -475m and excavate pump chamber and drill minibore hole.

Plugs

- Flood to equilibrium and cast an underwater plug
- Bulkhead plug constructed on the curb
- Plug, on top of a French drain on the muck pile.

CONSTRUCTION OF PLUG

After dewatering the shaft the water level was maintained at -439 metre elevation, the shutter was stripped out and the scheme developed for the salvaging of the shaft could be implemented.

This method entailed the constructing of a French drain and structural concrete plug, whilst continuing to pump with one submersible pump with another commissioned as a standby. A spare pump was kept on surface. (See Figure 4)

The steps involved in the plug construction were as follows:-

1. Install 2 x 900mm draft columns above the muck pile.
2. Install 7 x 50mm vertical Cementation injection pipes.
3. Tip 4m of washed plums on top of the muck pile.
4. Discharge two metres of washed 19mm stone down the concrete pipe on top of the plums.
5. Place PVC and geofabric sheets on top of the French drain above the water line.
6. Erect sacrificial scaffold and tightening pipes.
7. Cast 15 metre concrete plug.
8. Cure the plug.
9. Tighten the plug.
10. Remove pumps and blank flange draft columns.
11. Start reverse flow accompanied by cement grout intrusions.

SUMMARY AND CONCLUSIONS

The salvaging of the shaft was a success and a tribute to all those involved. The experience was not only an example of the benefits of client / contractor cooperation and joint participation in problem solving but was a technological achievement which involved the application of all the specialised Mining, Drilling and Engineering skills of the project team and contractor.

Having said this, should this method be considered for future shaft water intersections? Was it efficient?

Each water intersection has to be assessed for its own peculiar characteristics, depth, pressure, volume and pumping facilities. The method utilised here, might not suit another set of conditions. The greatest risk was the possibility of failure of the Pleuger pump during plug construction. This risk was effectively minimized by the initial availability of three commissioned pumps.

In terms of duration, the construction of the French drain, plug, curing, tightening and capping took only 26 days of the five months and one week salvage period.

The drilling, blasting and mucking of the 26 metre of plug, French drain and grouted muck pile from -424m to -450m only took 14 days.

The bulk of the time, nearly three and a half months was taken up with the reverse flow and injections, which took 40 days; and the redrilling, injections and additional covers took 63 days.

The reverse flow technique is the key to sealing exposed aquifers of this nature. Could the reverse flow and grout intrusion process have been made more efficient in terms of time? Supercharging the reverse flow process by increasing the feed pressure through a battery of pumps was considered, but the draft column pipes were limited to 7MPa and there were water supply quantity constraints.

Due to the large grout acceptances a number of additives were considered to reduce cement costs.

Slagment and OPC in a 50:50 mix, but slagment has no mechanical strength.

Pulverized Fuel Ash (PFA) could be mixed with the grout, this provides a more pumpable grout but increases setting time.

Tailings were considered but rejected on environmental grounds as they could contaminate the water table and choke off fine fissures.

Cement / water ratios were debated at length, most of the grout was intruded at between 1,5:1 and 1,8:1.

Extremely thick grouts of as high as 2,3:1 to 2,5:1 were pumped for short periods.

Greater acceptance was achieved at the lower ratios where the pumps were more efficient.

Specialized chemical grouts were considered but not employed as it was feared they may have jeopardized the ultimate success of the reverse flow intrusions.

Coloured dyes were used to indicate coupling between intrusion pipes and independent pathways into the fissure.

Isotopes were considered to establish cement travel but not used.

On three occasions the reverse flow process and grout intrusions were stopped to determine the fissure flow. This confirmed that the intrusions had reduced the flow to 19 000 lph and later to 14 000 lph giving some faith in a seemingly eternal and possibly fruitless process. In retrospect these checks probably dislocated some of the accretion that had taken place and this was noticed in reduced pressures when the flowback was stopped and the reverse flow started up again.

The introduction of sodium silicate just before the reverse flow stopped and the intrusion pipes blocked was probably coincidental and not the reason for the final seal.

Pumping of high pressure water to re-open pathways through the grouted shaft bottom to extend the reverse flow and intrusions probably caused the South Pipe gasket to leak.

The reverse flow and grout intrusions seemed to run their own natural course and eventually a seal was obtained after a Biblical 40 days and 40 nights. How this process could have been accelerated is the subject of continuing debate. The extended drilling programme did confirm that the reverse flow had effectively sealed the fissure.

The probe drilling, injections and additional cover drilling took the lion's share of the time and it is a moot point as to whether this period could have been shortened without endangering the success of the programme. Initial consolidation problems below the plug were later resolved by the utilisation of a specialised chemical grout. The drilling programme was extensive and time consuming but necessary to establish the confidence that the water had been sealed. Utilising the S-140 drifters on cradles with controls proved more effective than S-36, Kempe and S-30 machines.

No significant water was intersected after the 7 360 tons of cement were intruded by the reverse flow process. The additional covers at -424,1m, -432,5m and -442m were basically all dry and accepted a further 204 tons of cement and 4,1 tons of Super Grout.

The concern that water might travel back along the fault and break back into the shaft at the lining fault intersection proved to be groundless, confirming the fact that the fault had been adequately tightened and treated on the previous covers.

The fact that the tightening phase was cut short by the collapse of the bottom North pipe proved not to be a problem, as the 416 tons of cement injected during the drilling phase more than adequately tightened the plug and was confirmed during the plug removal. The cause of collapse of the bottom draft columns as to whether this was due to tightening and/or casting continues to be deliberated.

The trapped pump was recovered.

The grit within the fault proved extremely difficult to consolidate and was responsible on numerous occasions for choking the suction on the pump. The inflow point turned out to be at the intersection of some significant geological features. It occurred where the steeply dipping Broken Arrow fault intersected the giant chert breccia above the Malmani dolomites of the Transvaal series. The chert-breccia-dolomite contact also turned out to be 39 metres higher than originally projected.

The revised cover round described for the dolomitic sequence is a more intensive pattern, leaving little to chance but taking significantly longer to drill and inject.

The connection of the Main shaft with a sleeved large diameter hole to a pump chamber in the Ventilation shaft to provide an emergency water handling facility to surface also proved to be a success, saving the excavation of an intermediate pump chamber in the Main shaft.

Shaft floodings are relatively infrequent occurrences and certainly to be avoided. Full cover precautions were only expected to be taken in the dolomites.

Nevertheless the salvaging of the shaft was a success and this paper adds to the few documented precedents.

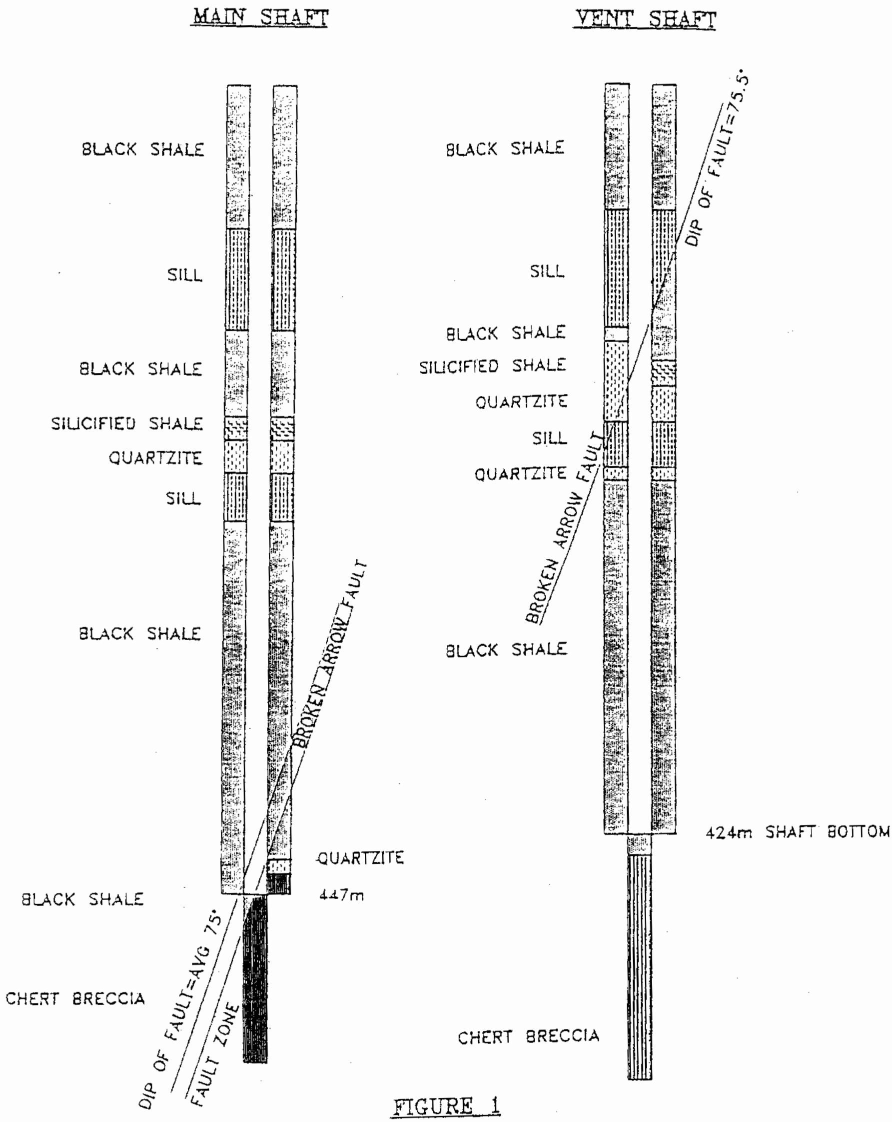
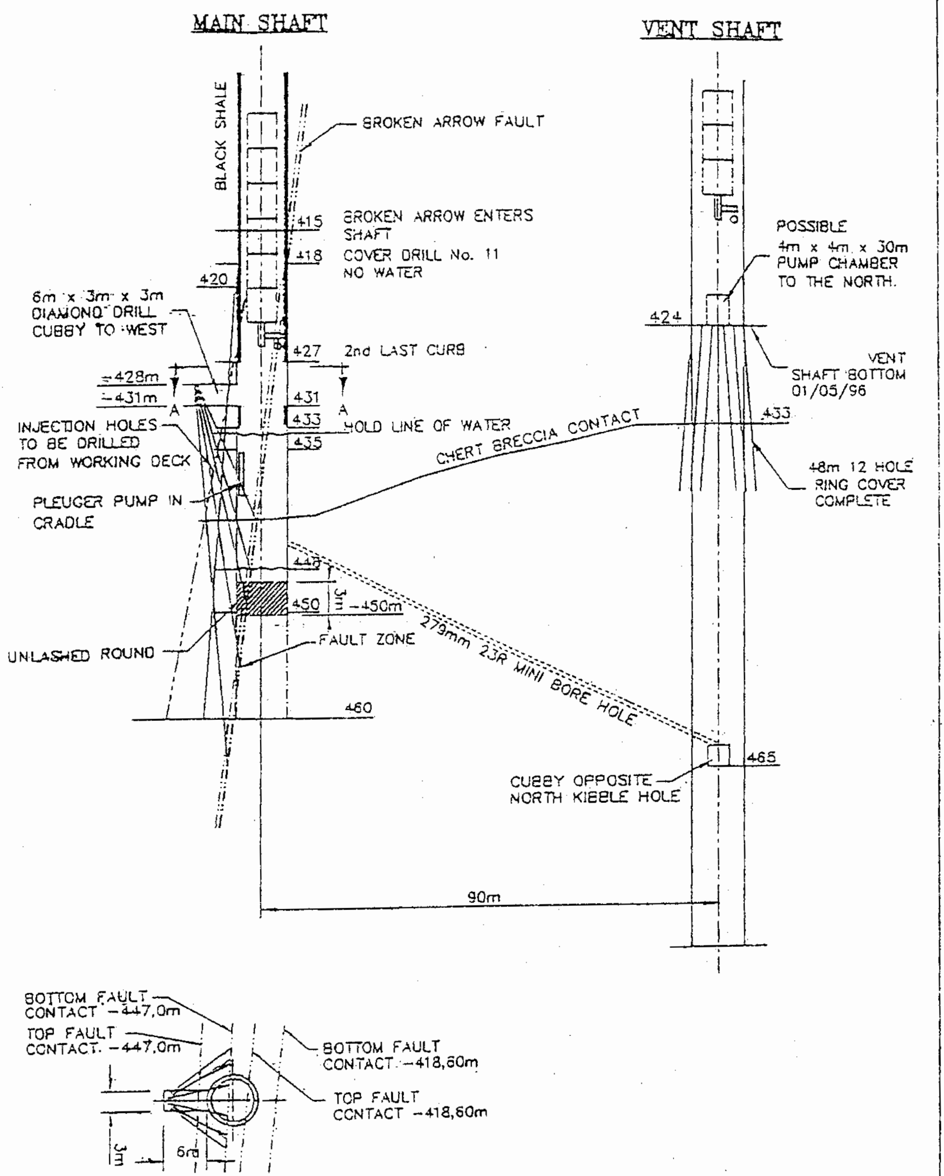


FIGURE 1

GEOLOGICAL SECTION SHOWING SHAFT ELEVATIONS ON THE 1st MAY 1996



SECTION A-A

FIGURE 2

OPTIONS

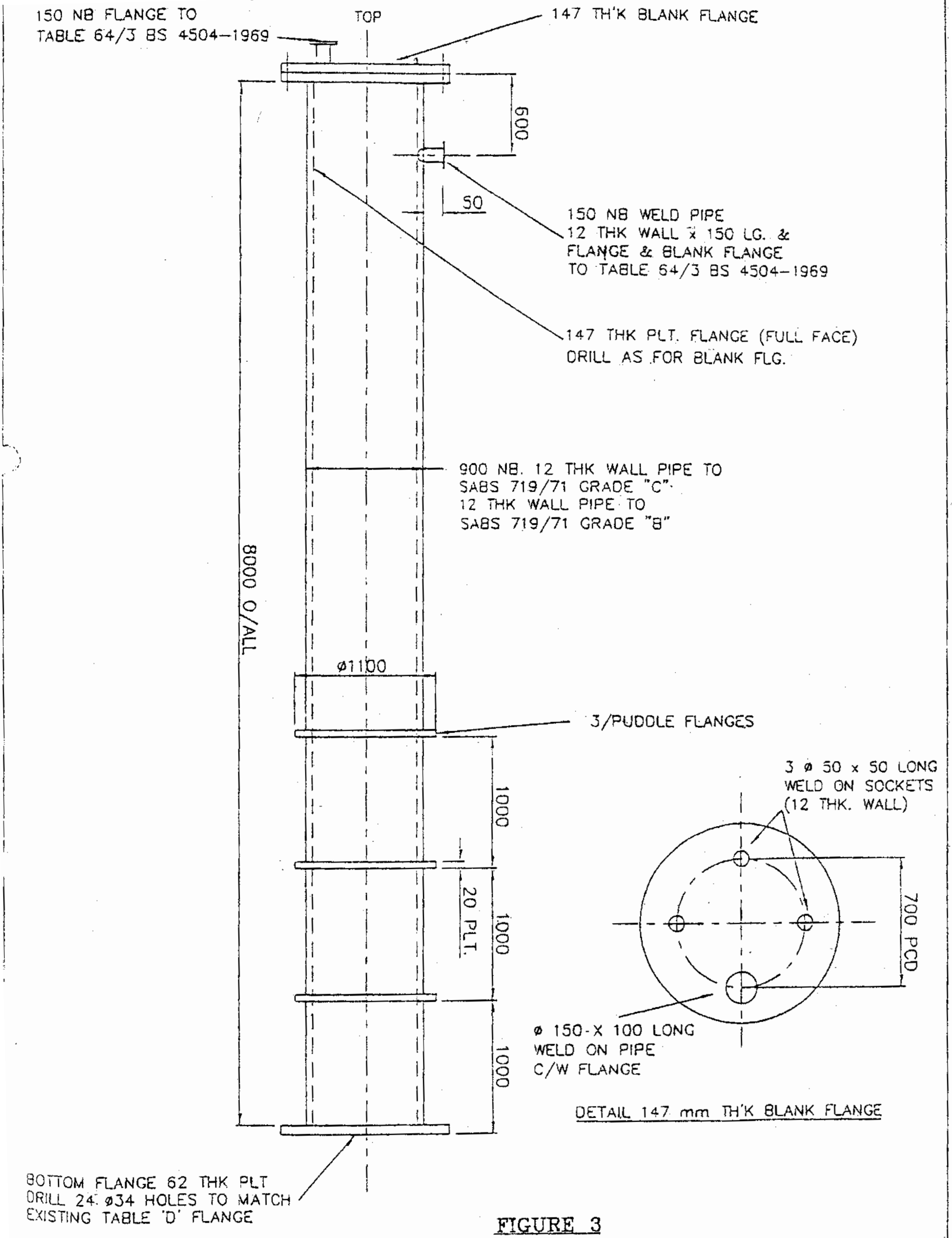
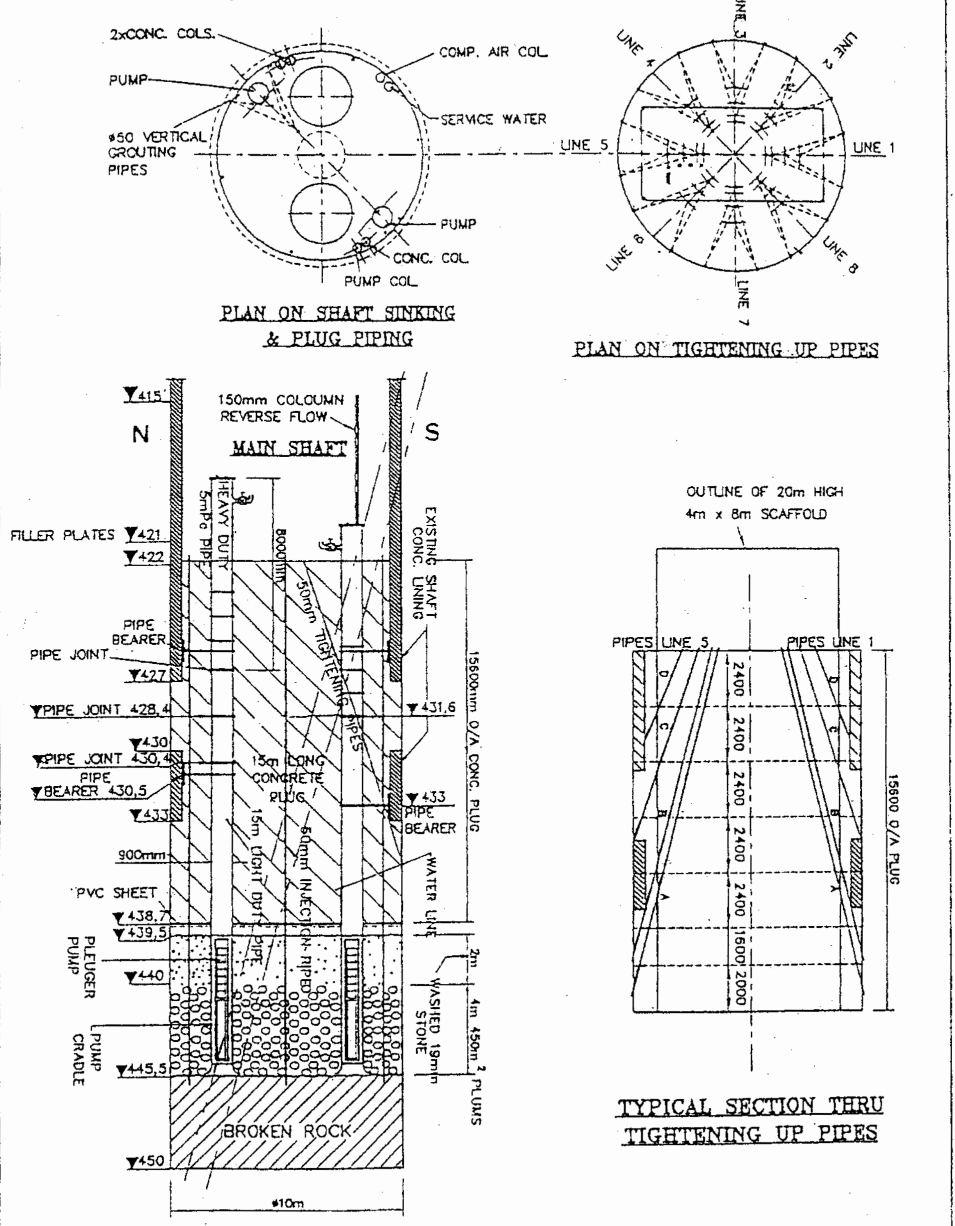


FIGURE 3

900 mm PIPE WITH FLANGES AND PUDDLE FLANGES

TOP DRAFT COLUMN



DIAGRAMATIC SECTION THRU. PLUG

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FIGURE 4

STRUCTURAL CONCRETE PLUG

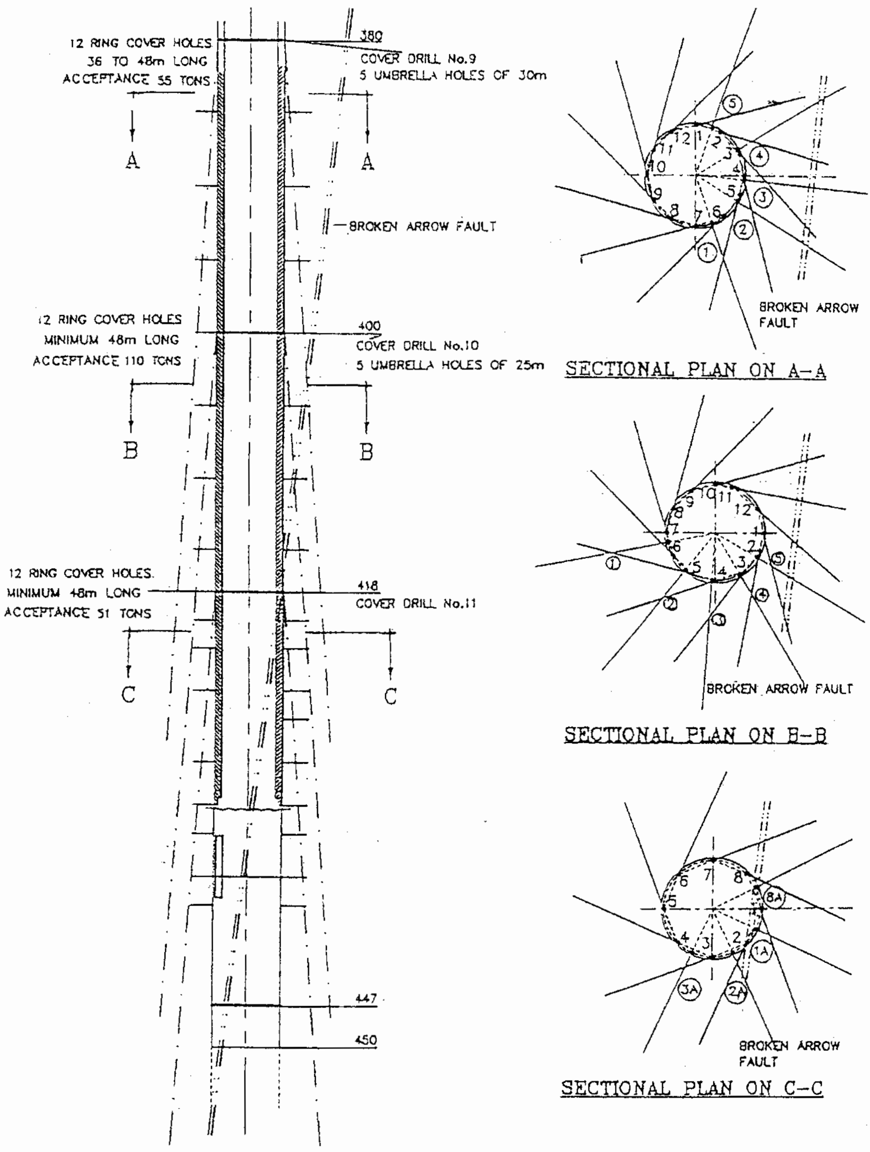

FIGURE 5

COVER ELEVATIONS 9,10,11

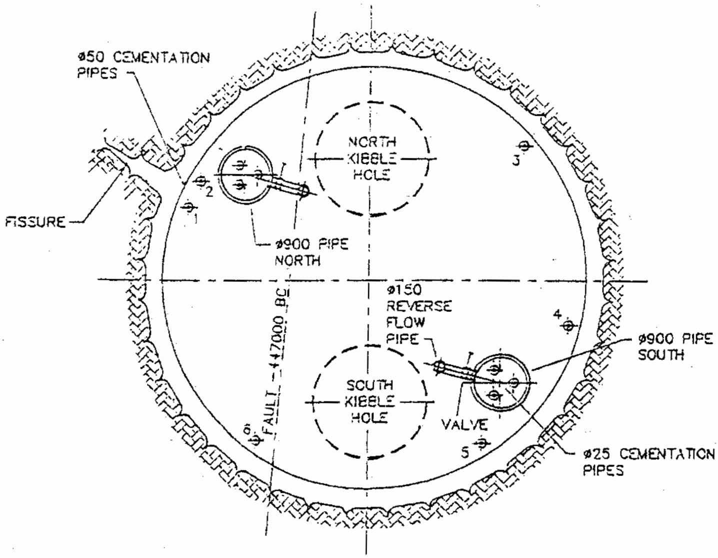

FIGURE 6

PLAN VIEW OF REVERSE FLOW PROCESS PIPES.