MOAB KHOTSONG MINE

A Mining Engineer's Perspective on the Application of Steel Fiber Reinforced Wetcrete as a Support Medium in an Ultra Deep Level Mine

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Editor's Note: This is the first half of a two-part article. The second part will appear in the Mining issue of Shotcrete Magazine *in August, 2000.*

1.0 SYNOPSIS

Moab Khotsong Mine has, over a period of two-and-a-half years, successfully placed 36,000 m^2 (390,000 ft^2) of steel fiber reinforced wetcrete as support to a large number of underground excavations. As a result of these successes, its application will continue to expand. This expansion will be due to the implementation of this system as part of a support system for tunnels advancing in the deeper portions of the mine 2700 m (8850 ft) below surface.

The purpose of this article is to cover the history and experience gained in the use of steel fiber reinforced wetcrete as a tunnel support in an ultra deep level environment.

2.0 BACKGROUND TO MOAB KHOTSONG MINE

2.1 LOCATION

Moab Khotsong Mine is located in the North West province of South Africa, 25 km (16 mi) southeast of Klerksdorp, as illustrated in Figure 1.

2.2 GEOLOGY

In basic terms, the gold bearing reef to be mined at Moab Khotsong Mine exists in two distinct blocks/packages created by the intersection of the reef by the Jersey Fault, a structure that faults the reef down vertically by some 1200 m (3900 ft) (see Figure 2).

As a result, the gold bearing reef to be exploited is accessed at its shallowest point, 2100 mbc (6900 ft bc) (mbc = mean depth below collar/surface), and at its deepest point, 3700 mbc (12,140 ft bc). All access excavations will be in the foot wall quartzite's known as the MB10s.

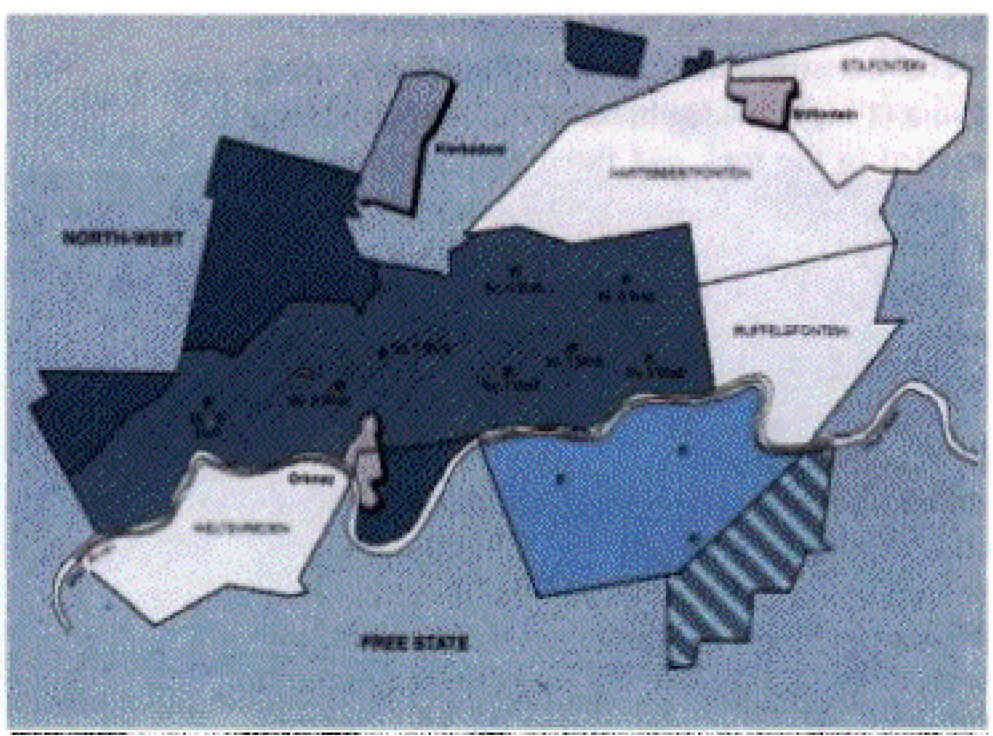


Figure 1: Klerksdorp mining district showing location of mine.

2.3 ROCK ENGINEERING CONSIDERATIONS

As outlined above, the majority of access excavations will be sited in the foot wall. What should be emphasized here is the actual poor quality of this rock mass. It is heavily jointed with cohesion less bedding planes.

In addition, the rock engineering design allows for the probability that some of the access development may intersect shales with a low compressive strength of 80 MPa (11,000 psi) at depths of around 2900 mbc (9500 ft bc) (see Figure 3).

2.4 THE UNDERGROUND ACCESS SYSTEM

The current design of the reef access system to be implemented at Moab Khotsong Mine consists of the following major components (see Figure 5).

It should be noted at this point that the current design is subjected to continuous review and is tested on a regular basis against new technology and methods for potential benefits. Hence, the detail design outlined below may change as the project advances.

2.4.1 The Main Shaft

The main shaft is a composite shaft 10.7 m (35.1 ft) in diameter and goes to depth of 2350 mbc (7700 ft bc). It functions as a conduit for men, material, rock, ventilation and all reticulation requirements (see Figure 6). During the period of September 1998 to August 2001, it is planned to go underneath the commissioned shaft and deepen the men and material handling component of the shaft to a depth of 3100 mbc (10,170 ft bc).

2.4.2 RV Sub Shaft

A sub shaft is situated as shown in Figure 6 that will act as a conduit for the handling of rock and ventilation from a depth of 3100 mbc (10,170 ft bc). For a period of 34 months, from August 1998 to July 2001, a mid-shaft loading system will operate on 85 and 95 level to allow rapid access to the upper reef blocks while concurrently completing the development of the RV Sub Shaft with its associated infrastructure (see Figure 4).

2.4.3 Decline System

From a depth of 3100 mbc, a twin decline system will be sunk to a depth of 3522 mbc. The advantage of such a system is that contact with the expected shale horizon will be of a limited nature and hence, will improve the strata control (see Figure 4).

2.4.4 Sub Men and Material Shaft

Finally, a subvertical men and material shaft shall be sunk by means of a slipe, line and equip sinking program from 3042 mbc (9981ft bc) to a depth of 3522 mbc (11556 ft bc). Its purpose will be to handle the movement of men and material to the various sublevels (see Figure 4).

The above was a brief outline of the project's Reef Access System that highlights a number of key issues that have influenced the decision to use steel fiber reinforced wetcrete as a primary support medium. They are:

- Depth of excavations (2400 mbc) (7875 ft bc).
- Size of excavations (environmental requirements).
- Quantity of large excavations required.
- Quality and strength of rock mass.
- High rate of development required for the access tunnels.

3.0 THE APPLICATION OF STEEL FIBER REINFORCED (SFR) WETCRETE AS A SUPPORT MEDIUM

3.1 WHY SPRAYED CONCRETE?

3.1.1 Background

Moab Khotsong's first exposure to sprayed concrete came more out of necessity than experimentation. During the main shaft station establishment phase, extremely poor ground conditions where encountered that resulted in a number of large volume collapses. As a result of these collapses, it was immediately identified that the rock mass needed to be rapidly supported to prevent further deterioration. The resulting support recommendation was for long anchors, grouted slings with wire mesh and lacing, and a layer of shotcrete. The purpose of the shotcrete was to seal the excavation rock mass, but also to act as corrosion protection for the wire mesh and lacing.

In discussion with all parties concerned, and considering the threat to the Shaft Sinking Program, it was decided that an alternative system of support must be sourced that would meet with the following criteria:

- Meets the same support requirements as the initial recommendation.
- A quick, safe preliminary support.
- Can be applied in large excavations with the minimum of delays.
- Has a fast application rate and is cost-effective.

3.1.2 Selection of Support Type

After detailed researching of the mining and tunnelling industry in South Africa and internationally,

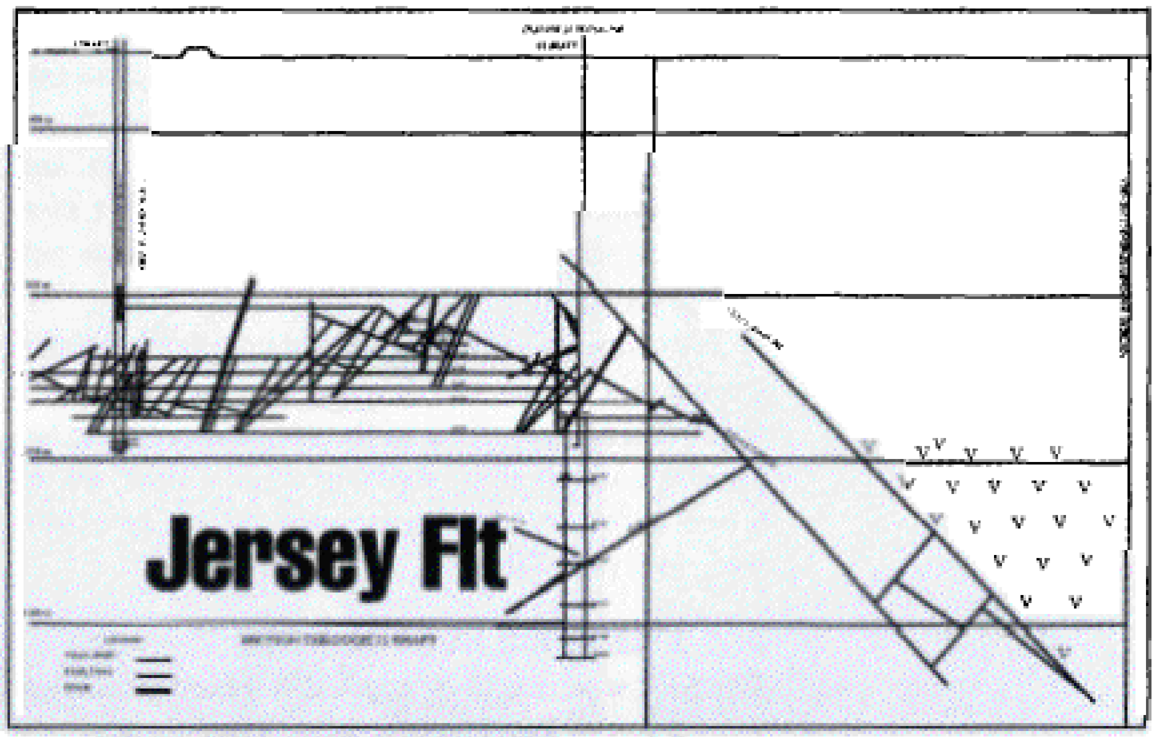


Figure 2. Section showing jersey fault.

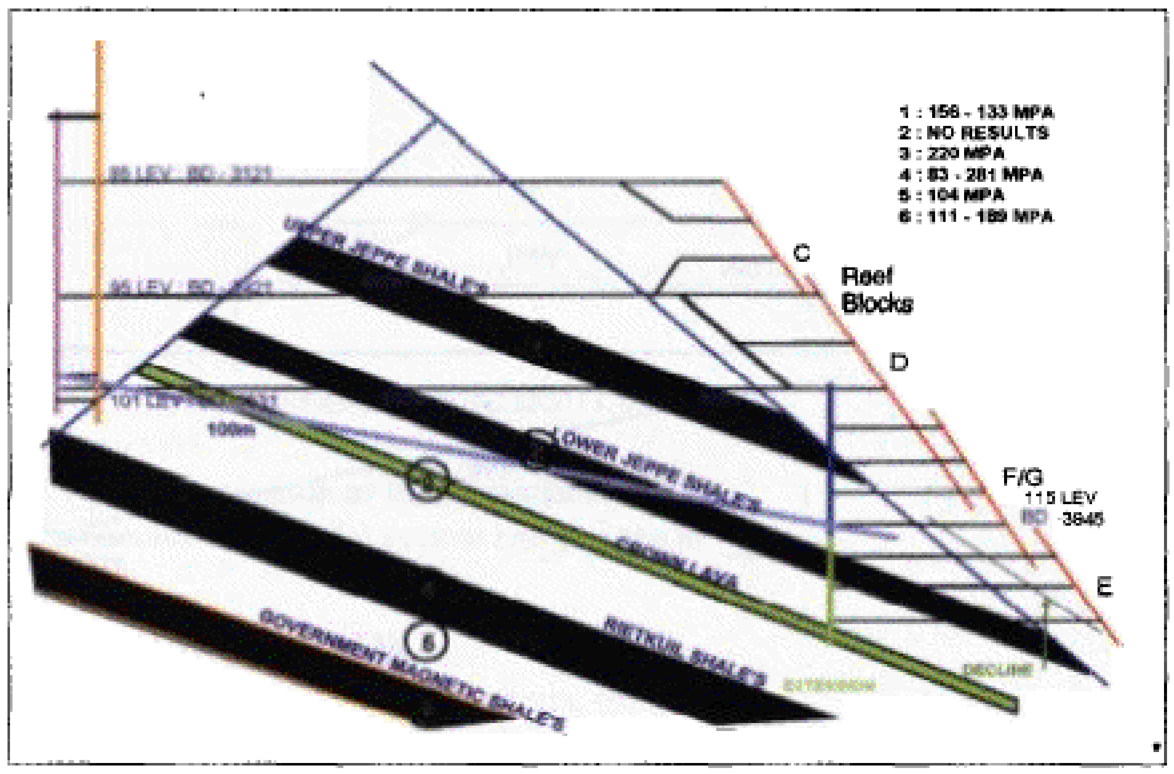


Figure 3: General location of shales.

the product that came closest to the criteria outlined above was that of sprayed concrete. However, there were a number of criterion that had to be met before this product could be considered as suitable. They were:

- Sustainable mix quality.
- Good workability.
- Consistently meet with support requirements.
- Minimal degree of rebound.
- Can be distributed with existing concrete handling infrastructure.
- Ease of manufacture.

In addition the support requirements determined by rock engineering were:

- Energy absorption of 700 J.
- Design compressive strength of 48/60 MPa (7000/8700 psi).
- In-situ strength of 41 MPa (6000 psi).
- Early-age strength of 0.5 MPa (75 psi) in 1.5 hours.

3.2 MIX DESIGN

The first step was to design a sprayable concrete product that would meet all of the criterion outlined above, inclusive of the support requirements, and at the same time could be handled through a conventional shaft sinking concrete manufacture and delivery system.

In co-operation with a supply company, the following mix design was developed to meet the above requirements, resulting in the sprayed concrete becoming a much more sophisticated product, which is now known as steel fiber reinforced wetcrete (SFR wetcrete) (see Table 1).

3.2.3 Handling Requirements

The SFR wetcrete to be applied is mixed on surface at a normal surface batching plant. Once the wetcrete has been manufactured, it is pumped a horizontal distance of 200 m (650 ft) to the main shaft to an open-ended steel pipe. The wetcrete then free-falls in this pipe a vertical distance of 2400 m (7875 ft) where it is then received by another concrete pump. This unit then pumps the product a further horizontal distance of 150 m (500 ft) to the spraying system (see Photos 1, 2 and 3).

On reading the above description, one can see that the product mix design must allow for a high degree of handling. It is for this reason that additional additives are added to the mix (see Table 2).

3.3 DETAILS OF THE SYSTEM AND EQUIPMENT USED

This application system can be subdivided into a number of key units, namely:

- Surface manufacture and transport.
- Vertical Transport (down the shaft).
- Horizontal Transport (supply).
- Application equipment (spraying unit).

3.3.1 Surface Manufacture

All the products discussed above (excluding TC 766) are, after being weighed and measured to ensure the correct quantities, added at the J-pan mixer. Note: the J-pan mixer used has a capacity of 0.5 m^3 (.65 y^3) and an effective mixing time of 5 minutes. Once mixed, the SFR wetcrete is pumped to the shaft head gear. The key issues to be monitored in this process are:

- Quality of stone (within 5 mm (1/4 in) range).
- Weight of added products.
- Moisture content of material.
- Cement-to-water ratio.
- Mixing time to ensure proper mixing of all components and proper distribution of fibres within the mix (to prevent balling).

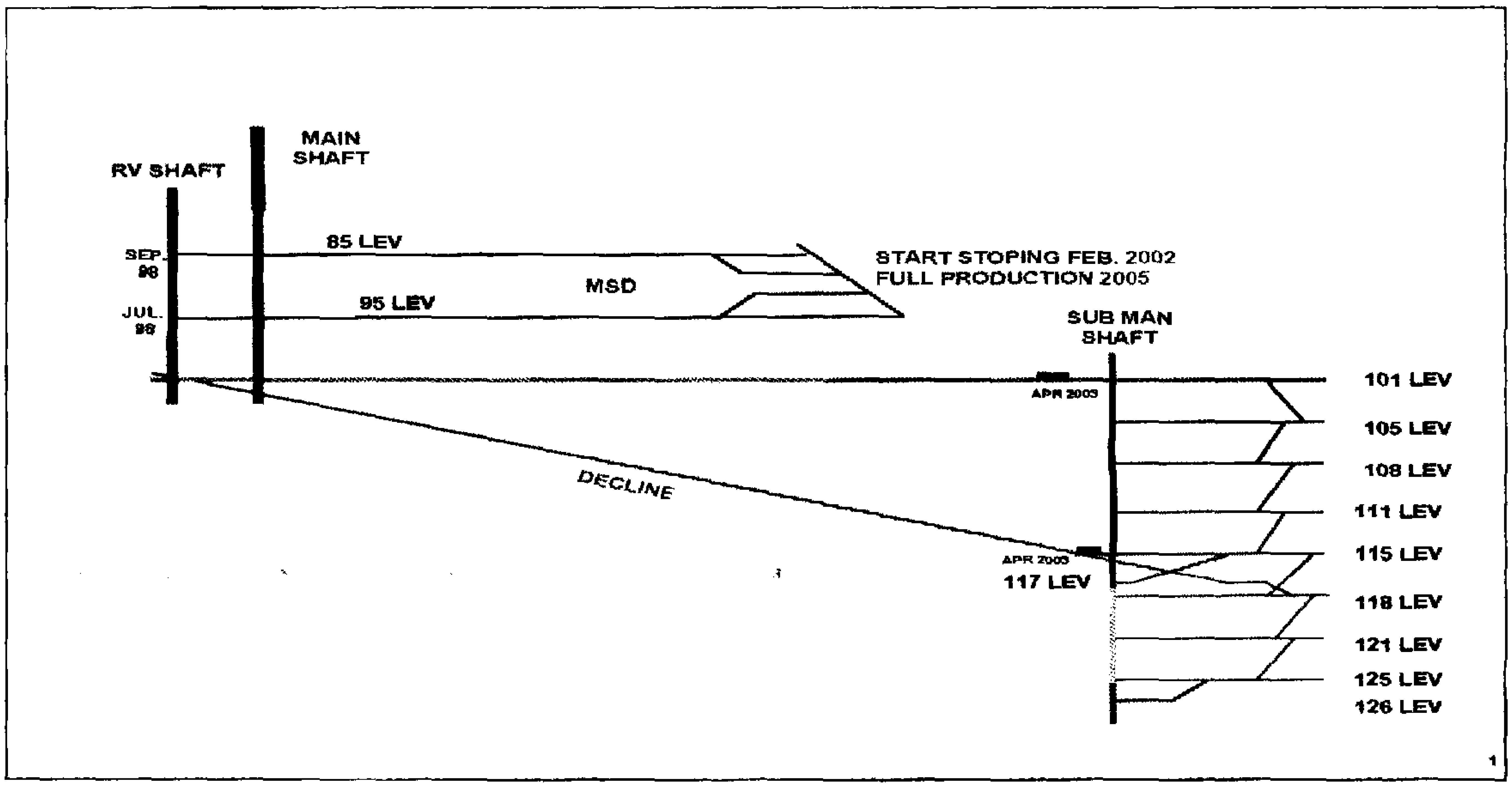


Figure 4: General reef access layout

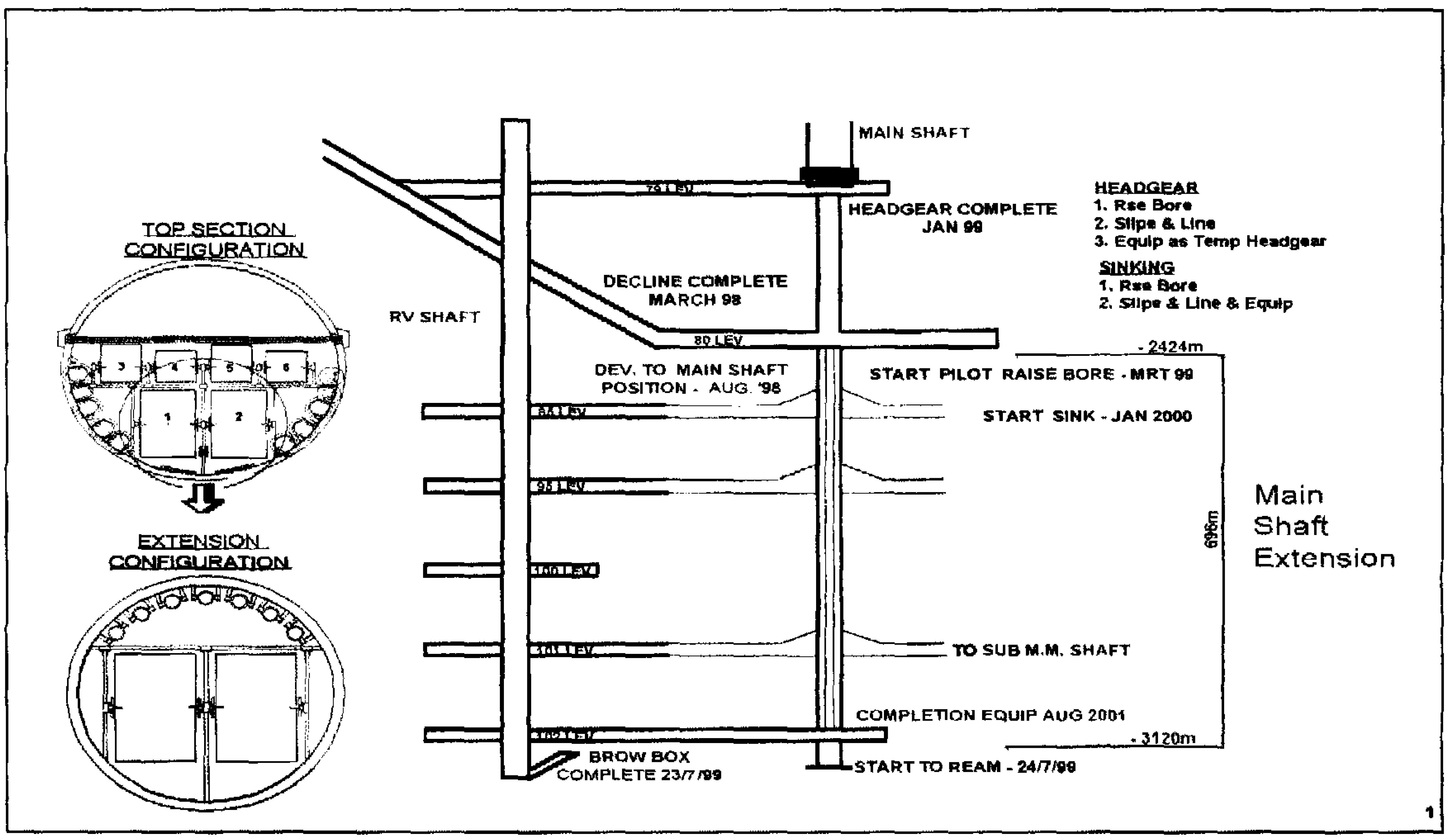


Figure 5: Main shaft layout

3.3.2 Vertical Transport

This consists of a vertical 150 mm (6 in) diameter concrete pipe (thick wall) in the shaft. There are four columns in the shaft that can supply various areas. These concrete columns discharge onto the levels, into either receivers or kettles. Receivers, due to less blockages and spillage, tend to be the preferred choice. It should also be noted that a kettle system requires a high degree of maintenance which, without sinking stage access, can prove to be difficult due to the kettle being above the station brow in the shaft. The key issues to monitor here are:

- Column must suit mix design, (four times diameter of the largest aggregate).
- Must be able to easily maintain the kettle or receiver.
- Spillage must be kept to a minimum.
- Vertical alignment of column vital to minimize wear.

Photo 1. Surface batch plant.

Photo 3. Underground Putzmeister.

Photo 2. Mixing plant.

3.3.4 Horizontal Transport

On delivery to the kettle or receiver, the SFR wetcrete is then either fed via the concrete hoses or receiver to another concrete pump. This concrete pump will then pump the product to the receiver of the SFR wetcrete pump (see Photo 4). The key issues here are:

- Proper re-mixing before pumping.
- Ensure supply rate matches spray rate.
- Place concrete pump in a steel tray to contain sludge and spillage.

3.3.5 SFR Wetcrete Pump

Up to this point, all the equipment used was of a standard range of equipment found in the sinking industry to carry out shaft construction. The spray pump finally selected, due to its ability to meet all criteria previously discussed, was the Meyco Suprema.

This pump is an electro-hydraulic machine with a sophisticated electronic PLC control and management system. This sophisticated control system results in short valve switching times and thus minimizes pulsing. The end result of minimizing pulsing is a more continuous flow in the delivery of the SFR wetcrete and hence, less rebound (see Photos 5 & 6). From the pump, the wetcrete is pumped to the applicator or spray system.

3.3.6 Spray System

The Meyco Robojet spray system was selected as a good match for both the required application rate of the SFR wetcrete and the Suprema pump.

The Meyco Robojet is a hydro-mechanical remote-controlled spraying manipulator and can be attached to various types of carrier vehicles—in our case, a normal Nissan back-actor excavator. In basic terms, this Robojet allows for the automatic linear horizontal cycling movement and circular movement of the spray nozzle. This means that the operator is then able to focus more on maintaining the nozzle at:

- 90° to the face
- The optimum distance from the face (1.0 to1.5 m) (3 to 5 ft)
- Optimum position to fill all cavities

A schematic of the total system can be seen in Figure 8.

3.4 OPERATING CREW

After a number of preliminary efforts, the following crew was decided on:

1 hydraulic/mechanical fitter
1 electrician

TABLE 1

PRODUCT	GROUP	QUANTITY/ M^3 (YD^3)
Pit Sand	Concrete Base	285 kg (480 lb)
Crusher Sand		905 kg (1525 lb)
5 mm (1/4 in) Stone		475 kg (800 lb)
Cement		450 kg (760 lb)
Silica Fume	Improver	30 kg (51 lb)
Steel Fibers (25 mm) (1 in.)	Reinforcing	35 kg (59 lb)
TCC 735	Improver	5 kg (8.4 lb)
TCC 766	Activator	15 kg (25.3 lb)

TABLE 2

PRODUCT	GROUP	QUANTITY/ M^3 (YD^3)
Rheobuild 3510	Pumping Aid	5.21 kg (8.78 lb)
Pozzolith LD10	Retarder and Plasticizer	5.01 kg (8.44 lb)
Delvocrete	5.01 kg (8.44 lb)	3.81 kg (6.42 lb)

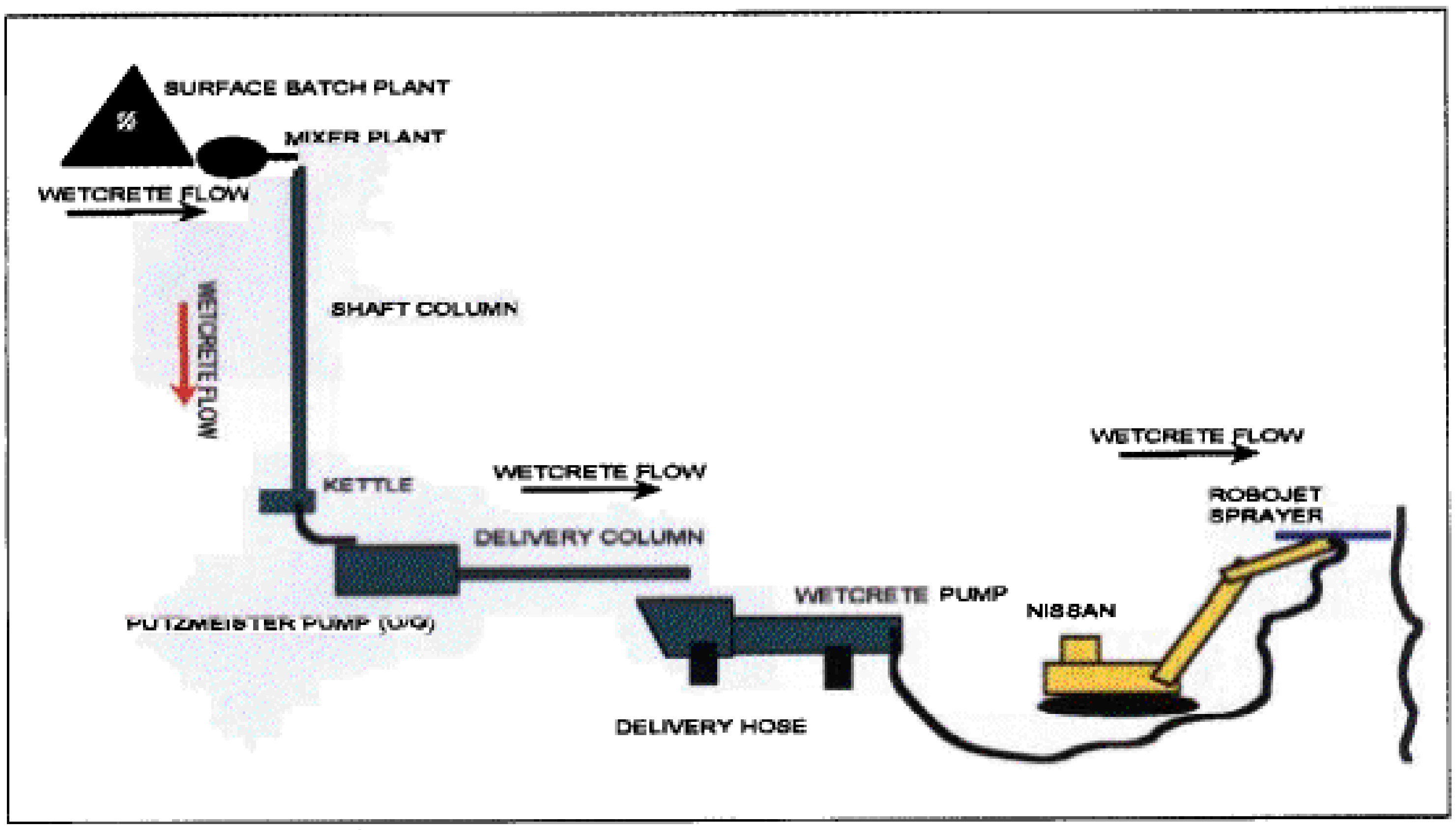


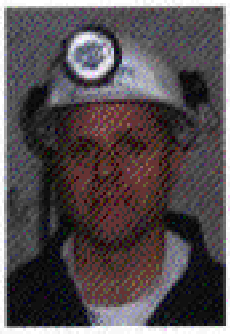
Figure 8: Schematic of wetcrete system.

The reasoning for the selection of artisans as the equipment operators was due to the artisans' ability to correct minor faults as they occur during a spray cycle, and hence minimize wastage. It is now no longer necessary to flush the system of all material while waiting for an artisan to arrive to repair the machine.

3.5 APPLICATION METHODOLOGY

There are a number of critical success factors that need to be adhered to, to ensure the successful application of SFR wetcrete as a support medium. The key ones are outlined below:

- Identify and carry out thorough spray site investigation (ease of access for cleaning, etc.).
- Install supply columns from shaft concrete pump to the spray pump (ensure pipes are level).
- Position equipment in an optimal position to allow full access to the area to be sprayed. Note that Suprema pumps can pump up to 300 m (1000 ft) if steel pipes are used.
- Mix a cement slurry and pump through the total system from concrete pump to nozzle. This ensures all pipes are lined and minimizes friction (and hence minimises the chance of blockages).
- Inspect visually excavation to be sprayed. Note variances in contours of the rock face to be sprayed. Bar off loose rocks.
- Ensure that the correct spraying method is maintained.
- Prepare facilities to receive flushing material (Paddocks).
- If equipment is not in use, ensure a storage facility is available so as to prevent any damage to equipment.
- Ensure good quality training for all crews.



Jonathan Buckley has been with Anglogold since 1988. His first position was that of Junior Mining Engineer, over the following years he held various positions within the company. From 1996 to 1999 he was Project Manager of Capital and Sinking operations at Moab Khotsong Mine; responsible amongst others for sinking a sub-shaft system to a depth of 3100m (10,170 ft) below surface. He is now a Manager for Anglogold Corporate office on a mining technology integration project.

Photo 4. Pump receiving hopper and delivery pipe.

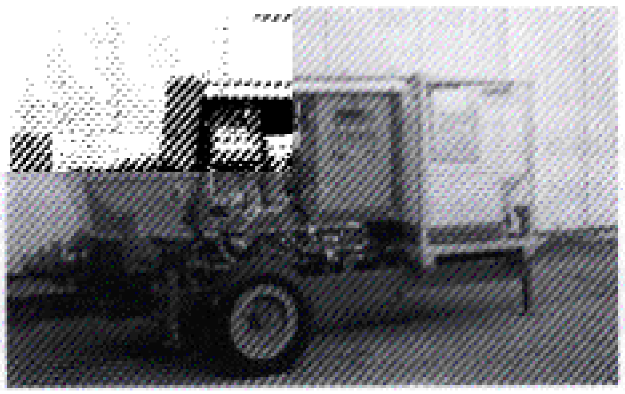


Photo 5. Wetcrete Pump (Suprema).

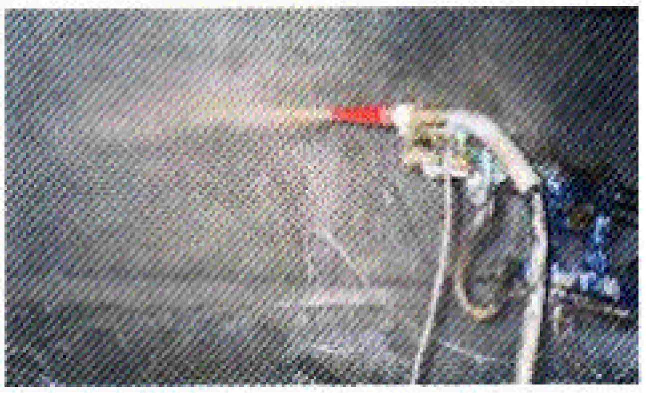


Photo 6. Robojet Sprayer