Shaft lining design and monitoring of the South Deep Twin Shaft System, Placer Dome Western Areas Joint Venture

SZ PETHÖ
Rock Engineering Department, Placer Dome Western Areas Joint Venture
Gauteng, Republic of South Africa

ABSTRACT

The South Deep shaft system has successfully been sunk through the backfilled VCR shaft pillar pre-extraction area. The VCR extraction in this area utilized a high performance crushed waste/classified tailings backfill, to limit stress and strain changes in the shaft barrel over the projected sixty-year life of the shaft system. Numerical models have been calibrated using stope closure/ride, backfill and haulage leveling instrumentation data, gathered over the past two and a half years. A high degree of confidence can thus be placed in the modelling results and hence in the predicted future shaft deformations.

VCR stoping around the shaft area is planned to continue for a further fifteen years after the shafts are equipped; hence allowance must be made in the support of the shaft sidewalls for a constant change in the overall stress and strain environment. Modelling results indicate that the monolithic concrete lining will be subjected to radial tensile stresses in excess of 8MPa over the life of the shafts. The cast concrete can be expected to withstand tensile stresses of up to 3MPa before the onset of cracking. For this reason it was decided to apply a fibre-reinforced shotcrete lining to the areas of the shafts where strain changes in excess of ± 0.2mm/m were predicted. Fibre-reinforced shotcrete has significantly higher ductility than monolithic concrete and will thus be able to tolerate higher strain changes.

The present wet shotcrete (wetcrete) design, quality control process and application methodology is discussed. The wetcrete application ensures a consistent high quality support membrane is applied to the sidewalls. This paper reviews the instrumentation program for the South Deep shaft, which ensures a continuous long term monitoring of the shotcrete and concrete linings. Eight rings of vibrating wire strain gauges have been installed in the Main shaft lining and nine rings in the Vent shaft respectively to monitor these strains. To date none of the 17 rings installed indicate any failure occurring and this is borne out by visual observations as well.

INTRODUCTION

The industry standard strain criterion of ± 0.2mm/m was used throughout for the analysis of the stability of a 300mm monolithic concrete lining placed in the barrels of the twin shafts being sunk at the South Deep Site, Placer Dome Western Areas Joint Venture (PDWAJV). Sections along the length of the barrels exceeding this criterion have been determined by elastic boundary element modelling. A high degree of confidence was placed in the results obtained from the numerical models through comparison with results obtained from both near and far field monitoring. The philosophy governing the pre-extraction of the South Deep shaft reef, the backfill strategy employed, the instrumentation results and the numerical modelling philosophy have been detailed by Raffield et al, 1998.

Three dimensional Fast Lagrangian Analysis of Continua (FLAC3D) modeling incorporating non linear rockmass behavior has been conducted to verify the response of a concrete lining to strains in excess of the design criterion. Based on both the results of elastic boundary element modelling and elastic/inelastic FLAC3D modelling, a joint decision was made to support a 352m length of barrel with fibre reinforced shotcrete (FRS). The FRS can tolerate strains, which would otherwise damage a conventional monolithic concrete lining.

Aspects of the shotcreting methodology from conceptual design to in-situ placement are discussed. A system of long term monitoring of the shaft linings is crucial for safety and operability. The choice of monitoring system for the harsh sinking environment and the predetermined outputs from the monitoring system is detailed, together with some initial results.

LOCALITY

The PDWAJV lies approximately 50km southwest of Johannesburg. The mine presently occupies a mining authorization area of approximately 1 481ha. The northern portion of the mining authorization area comprises gently northward sloping dolomite plain containing depressions typical of karst type topography. Southward, two prominent ridges separated by a dolomite inlier provide a suitable site for the mines surface shaft (South Shaft) with its associated infrastructure. Kloof, Libanon, Venterspost and Harmony Gold Mine at its western and northern extremities bound the mine, respectively. Figure 1 shows the position of the mine relative to surface infrastructure and neighbouring mines.

The South Deep orebody consists of two principal reef packages, the Ventersdorp Contact Reef (VCR), and the Upper Elsburg reefs (UE^S). The VCR unconformably overlies the UE^S and the orebody dips at an average of 18º from north to south. This sedimentilogical feature is referred to as the UE subcrop, which bisects the property in a NE-SW orientation. T he Upper Elsburg package widens towards the east and attains thicknesses of up to 130m at the eastern boundary of the property.

The Upper Elsburg package consists of a number of individual conglomerate bands, which will be mined using massive mining methods employing drift and fill, benching as well as long hole open stoping. The depth of the South Deep orebody ranges between 2 400m below surface at the northern boundary of the property and extends to beyond 3 500m below surface in the south.

The current ore reserves of South Deep are estimated to be able to sustain the mine at full production for 50 years. After the commissioning of the shaft system, monthly production will increase to 220000 reef tons and 15 000 waste tons per month.

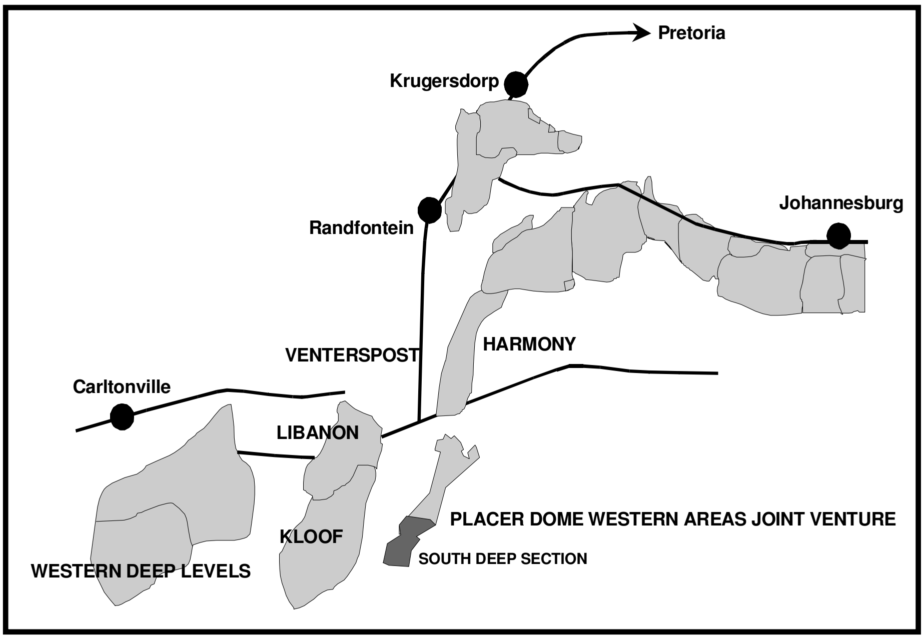

Figure 1
Locality plan of PDWAJV showing the position of South Deep

The twin shafts currently being sunk at the South Deep Site will form the second surface shaft system on the lease area that will facilitate the extraction of a wide orebody sited east of this new shaft complex.

SHAFT POSITION

The shaft system has been positioned to intersect the pre-extracted VCR stoping horizon situated in the north western sector of the South Deep orebody (Fig. 2). Positioning the shaft system east of the Elsburg subgroup would have led to severe damage to the shafts due to the massive mining that will be conducted in this area.

SHOTCRETE METHODOLOGY

The modelling results indicated that a support membrane other than cast concrete would be required to maintain the long term stability of a 352m length of shaft barrel. This support membrane would need to have sufficient long-term compressive strength, ductility and an ability to absorb strain energy without losing integrity. The characteristics of fibre reinforced shotcrete made this support medium the obvious choice. An on-mine shotcrete-working group was subsequently established to determine the shotcrete methodology from design to placement that will ensure adherence to predetermined specifications. The sections that follow briefly capture the chronology of events leading to the placement of high quality steel fibre reinforced shotcrete.

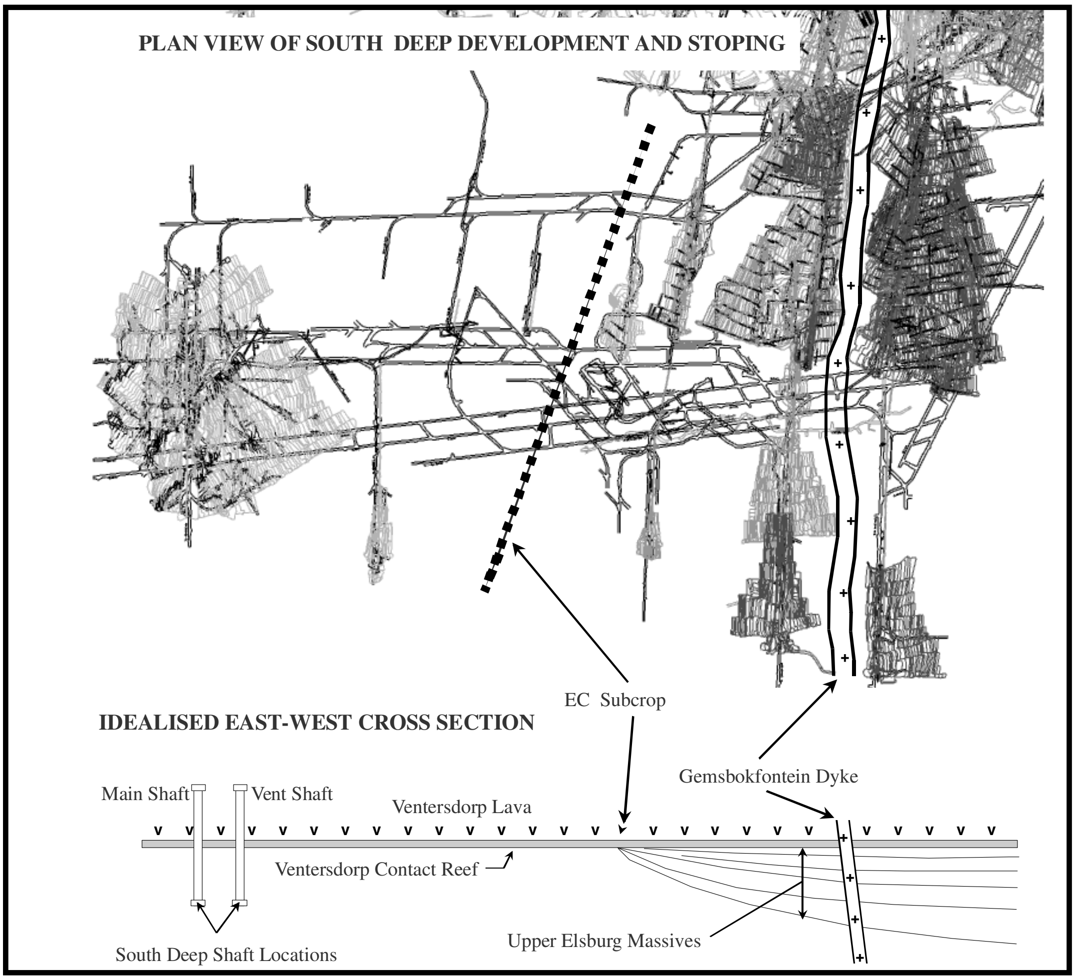

Figure 2
South Deep Shafts relative to geology of orebody

Wet Shotcrete

The process of applying shotcrete wet rather than dry stemmed from reasons specific to the current South Deep shaft system infrastructure:

- An existing surface concrete batching plant;
- Minimizing interference with shaft cycle times;
- Reduced bulk movement of material in and out of the shafts;
- Underground safety issues relating to material handling;
- Assured in-situ quality;
- Reduced rebound;
- Reducing dust levels in a confined environment;
- Reduced application times.

Reasons other than those stated above for the selection of the wet as opposed to the dry shotcreting process are well published and were considered in the selection process.

Design Criteria

The specifications for the type and quality of shotcrete to be placed in the 352m length of Main and Vent shaft barrels was determined from numerical modelling with due consideration for durability of a shaft system with a 60 year ‘life span. Design parameters assessed include ‘early age’ and long term compressive strength, in-situ strength, energy absorption capabilities and yield ability.

Compressive Strength and Energy Absorption

A maximum value of 35MPa for the horizontal component of stress change was predicted from elastic numerical modelling undertaken for the life of VCR stoping in the shaft pillar pre-extraction area. This value occurs close to reef intersection and is encompassed within the 352m area, demarcated for shotcrete application, as outlined in Pethö et al (1998). The application of a factor of safety (FOS) of 1.7 to the modelled horizontal compressive strength was used to determine the design compressive strength of 60MPa for shotcrete. The prerequisite set for all aspects of shotcrete design was that the placed strength should exceed a FOS of 1.5 with respect to the modelled horizontal compressive stress. Additionally, the placed shotcrete should be sufficiently impermeable to ensure long term durability of the fibre and concrete matrix. Using the European Federation of National Associations of Specialist Contractors and Material suppliers for the Construction Industry (EFNARC, 1993) specifications, the energy absorption criterion was set at 1 000 J for a 28-day plate test.

Sporadic incidences of strain bursting of shaft sidewalls occurred due to the existing horizontal stress differential prominent north-south joint sets and the traverse of Klipriviersberg lava with uniaxial compressive strengths in excess of 350MPa. The majority of strain bursts were located a minimum of 6m above the Main shaft bottom. This distance translates to a 48-hour period for the placed shotcrete to gain sufficient strength so as to arrest a block of rock subjected to a strain burst.

The early age strength and energy absorption requirements for placed shotcrete was determined using the following formula:

$$E = \tfrac{1}{2}mv^2 \qquad (1)$$

Where, ***E*** *is the kinetic energy;* ***m*** *is the mass of ejected rock and* ***v*** *is the velocity of ejection* *(3* ms^{-1}*).*

Using observed ejected block dimensions and the manipulation of equation (1), the early age strength criteria were specified as follows:

- ‘early age’ strength of at least 0.5MPa after 48 hours
- ability to absorb 400 J of energy after 48 hours

Mix Design

A program of testing incorporating various combinations of shotcrete ingredients commenced in October 1998. The EFNARC, 1993 specifications for testing of sprayed concrete was used for all shotcrete tests conducted to date. Table 1 illustrates the quantity of tests done for various fibre types and dosages.

Fibre Type	No. of Tests per Type			Dosages
	Cube	Core	Plate	(kg/m^3)
Dramix	71	15	76	15-60
Harex	22	10	61	35-60
Polypropylene	16	2	2	14
Dramix-polyp	12	0	13	15-25

Table 1
Quantity of tests conducted on fibre type and dosage

Based on the results obtained from the tests, the Dramix 40mm long fibre was chosen as the shotcrete-reinforcing ingredient that will provide the required ductility when combined with the chosen admixtures, aggregates, cement and water. The mix design formulated is contained in Table 2.

Shotcrete constituents	*1m^3 batch (kg)*	*0.5m^3 bulk bag (kg)*	*0.5m^3 Site batching additives (kg)*
CEM 1 52.5	475	-	237.5
Superpoz.	75	37.5	-
Silica Fume	38	19	-
6.7mm stone	262	131	-
Crusher sand	1 080	540	-
Stella sand	160	80	-
Fibrin	0.91	0.455	-
Dramix SS-a	40	-	20
Delvocrete	5	-	2.5
TCC 735	5	-	2.5
Glenium 51	1.98-3.17	-	0.99–1.59
Water	190-200	-	95-100

Table 2
Shotcrete lining mix design for the main shaft

The additives proposed for the mix is subject to change based on operational requirements. To date the whole 352m of the Main Shaft barrel have been successfully shotcreted using the mix design depicted in Table 2, while the Vent shaft is almost complete. This mix design has also successfully been applied to station brows and crosscuts developed from the shafts. An example of support designed for a station brow is shown in Figure 3 below.

Application Method

The three practical aspects integral to the maintenance of high quality placed shotcrete are discussed below.

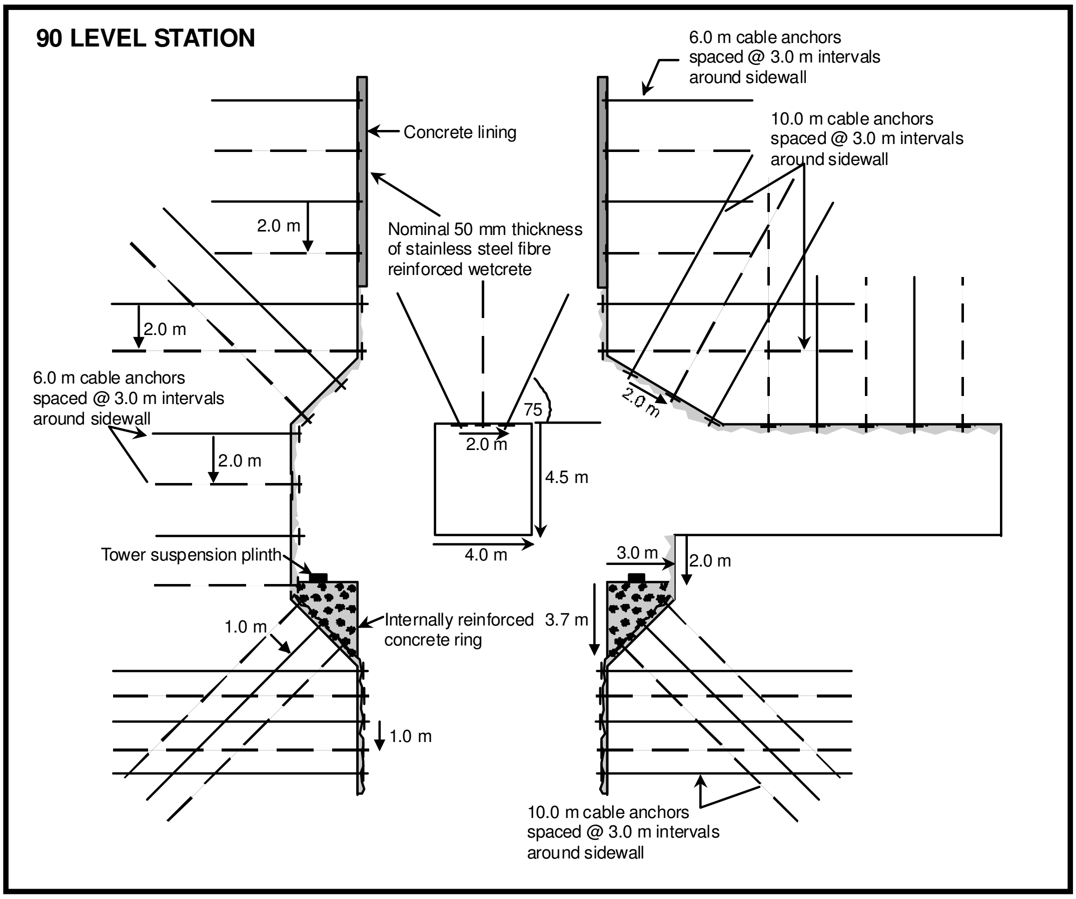

Figure 3
Typical station brow support using shotcrete and cable anchors

Batching

To ensure control over the processes of material handling, mixing and delivery of a high quality shotcrete, it was decided to batch on surface. The decision to batch on surface was further enhanced by the availability of an established concrete batching plant (Fig. 4).

Only minor adaptations were required to the existing plant. These adaptations have not hindered the inter-change between concrete and shotcrete batching. This aspect of inter-changeability was imperative to the recasting of concrete below the 352m destress zone.

A deterrent to underground batching was the wet environment which could have influenced the desired quality of the shotcrete e.g. alteration of cement-water ratio. It was logistically impractical to batch underground considering shaft time, material dispatching and space limitations. The surface batching operation has played a major role in the production of a predictable placed steel fibre reinforced shotcrete.

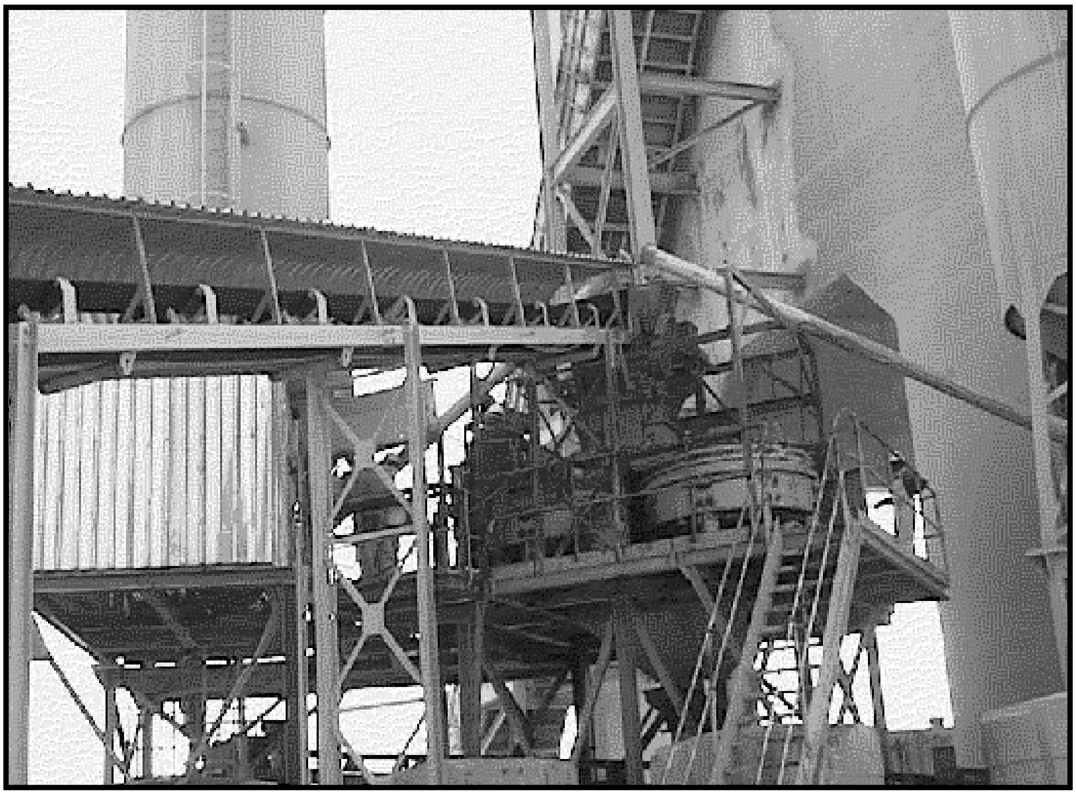

Figure 4
Photograph of the surface batching plant

Shotcrete Transportation

Two methods of shotcrete transport were reviewed i.e. slick line gravity feed to point of placement and ‘kibble’ transport. The slick line shotcrete transport method was rejected due to the following reasons:

- Potential pipe blockages;
- Pipe maintenance and the associated influences on the shaft schedule.
- Mix segregation within pipeline;
- The need for a receiver to contain dispatched shotcrete from the pipeline;
- Interrupted spraying due to batching capacity constraints.

The use of the ‘kibble’ to transport shotcrete eradicated the limitations associated with the slick line. The ‘kibble’ was modified to facilitate efficient receiving and dispatching of shotcrete. The top of the ‘kibble’ was sealed with a metal plate that had a small opening to receive shotcrete transported by a conveyor belt. After the ‘kibble’ received its full batch of shotcrete, an attached lid closed the opening. A conical shute was welded to the bottom section of the ‘kibble’ to facilitate gravity assisted dispatch of shotcrete. The shute end was fitted with a cylindrical pipe that was extended by a flexible pipe that fed into the Corretta Pump (Fig. 5). The cylindrical pipe had a manual feed valve installed.

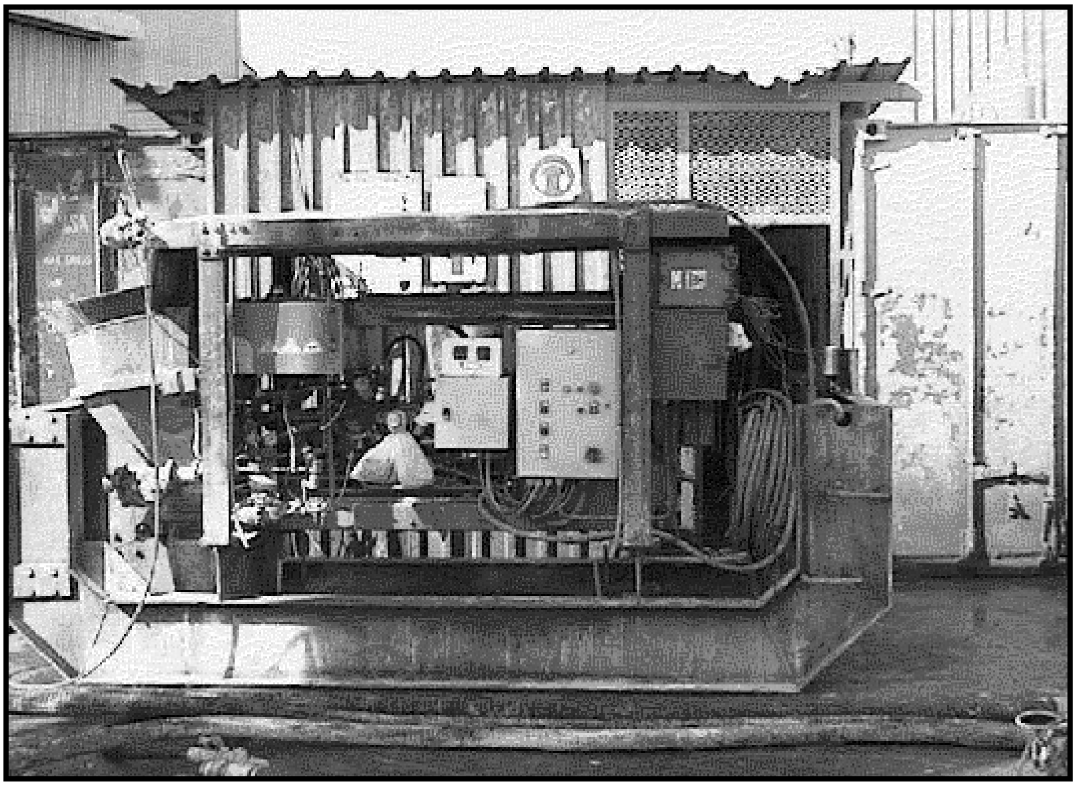

Figure 5
The Corretta Pump

The internal pipe area between the end of the shute and the valve was lined with a delvocrete-cement slurry to prevent blockage.

Spraying Technique

Although the robotic arm offered benefits with regard to consistent spraying thickness, it was not preferred for use in the sinking environment due to practical considerations (Figs. 6 & 7). The construction of a guide rail for the arm would hinder the operability of the 'cactus boom'. The guide rail would have had to be fixed from the bottom deck of the stage, implying stage movement to facilitate spraying.

Due to the flexibility of nozzle spraying, this technique was adopted. Four methods for nozzle spraying were reviewed. Spraying from the bottom deck of the stage was not favoured owing to the unavailability of space with regard to the placement of the Corretta Pump, accelerator barrel and the fixed 'kibble' position. Spraying maneuverability from a confined deck was not practically possible.

Constructing a platform for spraying that is suspended from the shaft sidewalls was rejected due to labour intensity, time consumption and safety related issues. The ingress and egress of construction material and the handling requirements further militated against the use of a platform.

Manual spraying from a basket suspended from the ‘cactus boom’ had limited success. Keeping the suspended basket stationary could not be achieved. An unsteady basket was not conducive to proper spraying. The risk of moving the basket containing people to new spraying areas countered the continuation of this technique. The handling of the pipe connecting the nozzle to the pump was cumbersome.

After a review of the methods available, spraying from the bottom of the shaft offered the most advantages. On completion of lashing, the pump and associated paraphernalia, accelerator barrels, a pre-constructed platform and personnel were lowered to the shaft bottom. Spraying was executed in 3m sectors around the barrel. The platform was used to facilitate spraying of the top 1.5m of exposed sidewall.

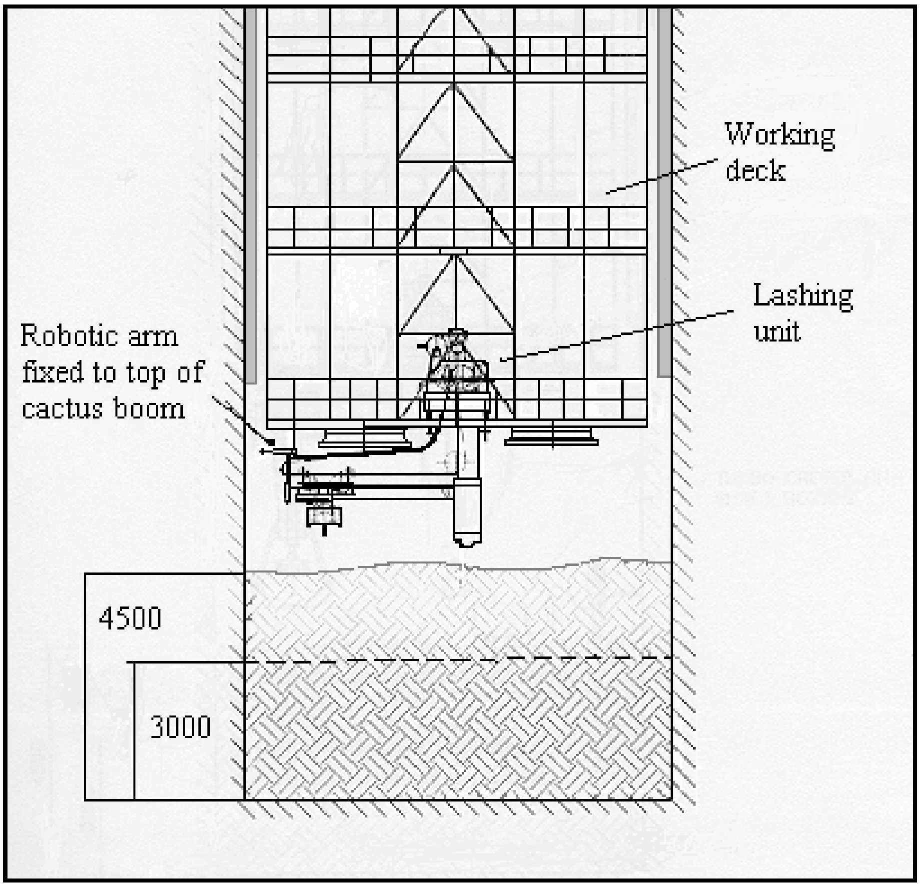

Figure 6
Schematic of robotic arm fixed to top of cactus boom

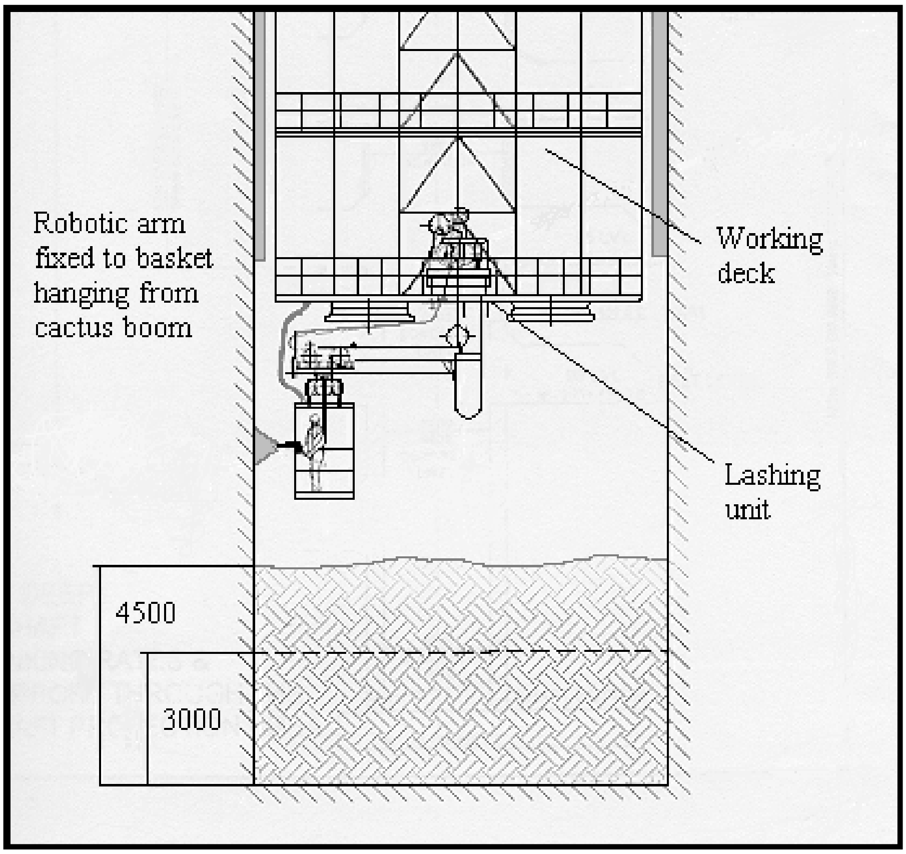

Figure 7
Schematic of robotic arm fixed to basket

Quality Control Measures

The design of shotcrete to meet the specifications obtained from numerical modelling made it prudent to have a quality assurance system in place to minimize deviations of placed quality from that designed. To ensure focus on quality assurance, all processes relating to quality control were outsourced. The quality assurance system proposed to control the manufacture and placement of shotcrete comprised a series of visual observations, checks and tests (destructive and non-destructive) to ensure that a minimum standard of quality can be ascribed to the material and the placement thereof. Quality control was subdivided into the three aspects that govern the quality of the placed material.

Manufacture of shotcrete

- The staff that operates the batching plant must be thoroughly trained in the operation thereof and be conversant in the use of additives and their effects.

- All mechanical, electrical and pneumatic functions and settings shall be checked for operability and settings prior to commencing of mixing.

Batching of Shotcrete

- The aggregate shall be tested for grading, moisture content and mass when unloading the material.
- Cementitious products must be stored to ensure no degradation of their inherent properties.
- The shotcrete mix must be carefully prepared by combining the ingredients in their correct proportions and order. The quantities of the chemical additives, fibre and water shall be recorded.
- Flow table tests are to be conducted on every batch of shotcrete produced.
- Concrete cubes and cores shall be taken from the batch plant to determine the compressive strength of the shotcrete at 7 and 28 days.
- Energy absorption tests shall be undertaken on specially constructed panels, which are sprayed at the point of batching.

Application of Shotcrete

- The persons responsible for the spraying of shotcrete shall be fully conversant and trained in all aspects of application.
- The equipment used for spraying must be checked for operability and settings prior to mixing taking place.
- The rock face must be prepared prior to application.

Testing Frequency

The frequencies of destructive, aggregate and cementitious product testing done on shotcrete batches are contained in Tables 3 -5 respectively.

Description of Test	*Frequency*
Compressive strength (cubes)	6 per 10 m^3 of shotcrete
7 days	3 per 10 m^3 of shotcrete
28 days	3 per 10 m^3 of shotcrete
Compressive strengths (cores)	6 per 3m of shaft lining
7 days	3 per 3m of shaft lining
28 days	3 per 3m of shaft lining
Energy absorption tests	1 per 3m of shaft lining

Table 3
Destructive test frequency

Test or Inspection	*Frequency*
Aggregate grading	1 per 10 m^3
Moisture content of aggregate	1 per 10 m^3
Aggregate masses	On delivery
Storage of aggregate	Daily
Chloride content	On request
Organic impurities	On request
Presence of sugar	On request
Soluble deleterious materials	On request
ACV and/or 10% Facts	On request
Alkali reaction of parent rock	On request

Table 4
Aggregate testing frequencies

Description of Test/Check	*Frequency*
52.5 RHPC Cement	
Delivery ticket	Each delivery
Sodium equivalent certificate	Each delivery
Silica Fume	
Mass per aggregate bag	Random
Packaging – waterproof	Random
Super-poz 5	
Mass per aggregate bag	Random
Packaging – waterproof	Random

Table 5
Cementitious product testing frequency

LONG TERM DEFORMATION MONITORING

A decision to implement a long term monitoring system in pre-determined locations in the barrel of the South Deep Main and Vent shaft stemmed from the assessment of the following factors:

- The maintenance of shaft integrity over a period in excess of 50 years.
- The quantification of risks and hazards associated with this major ingress/egress route over the 'life of the system'.
- The need for an 'early warning' or a detection mechanism that can stimulate a response to any rock related hazard that may impinge on the operability of the shaft system.

- The need for quantification of support reaction to both quasi-static and dynamic ground motions, that could prompt either modification or changes to installed support types and patterns relating to all PDWAJV mines.

- The conformance to the Mine Health and Safety Act, 1996 (Act No. 29 of 1996) in accordance to Guideline GME 7/4/118-AB1 issued by the Chief Inspector of Mines. Particular reference is made to Section 14 of the Rock Engineering Code of Practice for PDWAJV titled Monitoring and Control.

- To gain an understanding of rock mass behavior in an around the shaft barrel, thus promoting better design in the future.

Instrumentation Suites

Once the need for installing instrumentation in both the Main and Vent shaft barrels that could satisfy the short to long term monitoring needs was established, an analysis of available instrumentation types was conducted over a period of approximately three months. The criteria adopted for the choice of instrumentation to be used were predetermined as follows:

- Accurate measurement of deformations within tolerable error levels.

- Total cost of the system.

- Ease of installation.

- Automation capability of the system.

- Robustness of system given the environment of installation.

Types Reviewed

Table 6 depicts the types of instrumentation systems reviewed and briefly describes the limitations and benefits of the various systems. The system choice was based on the advantages outweighing the disadvantages using the criteria bulleted above as an analysis benchmark. Based on the analysis briefly described in Table 6, the vibrating wire monitoring system was decided as the type to be used for instrumentation of the Main and Vent shafts.

Instrumentation Type	*Limitations*	*Advantages*	*Choice*
Analogue systems	– Not robust – too dependent on environment – Limited success historically – No central read-out unit – Requires routine calibration – Limited sampling points	– Cheap – Simple data acquisition capabilities – Repeatable results	✗
Observational monitoring	– No early warning capabilities – Labour intensive – Subjective – Not quantitative	– Very cheap – Large number of sampling points	✗
Optical fibre systems	– Never implemented in a sinking shaft system – Limited expertise exists within RSA – Very expensive – Not robust on installation – impact resistance – Readout unit expensive – Environmental conditions effect readings	– Effective infinite number of sampling points. – Easy to install. – Extremely accurate results – Repeatable results	✗
Vibrating wire systems	– Limited readout points	– Less expensive than optical fibre systems. – Extensive expertise exists within RSA – Easy to install – Centralized readout units – Can be made fully automated – Accurate – Tried and tested – Repeatable results	✔

Table 6
Review of various instrumentation systems available

The Vibrating Wire Strain Gauge Monitoring System

System Description

The vibrating wire strain gauges from GEOKON (Fig. 8) are designed for direct embedment in concrete or shotcrete. The gauges may be positioned either by means of wires wrapped around the body or by attachment to a rosette, which will hold the gauge in a predetermined orientation in the concrete/shotcrete. The strain gauges are 15.24 cm in length.

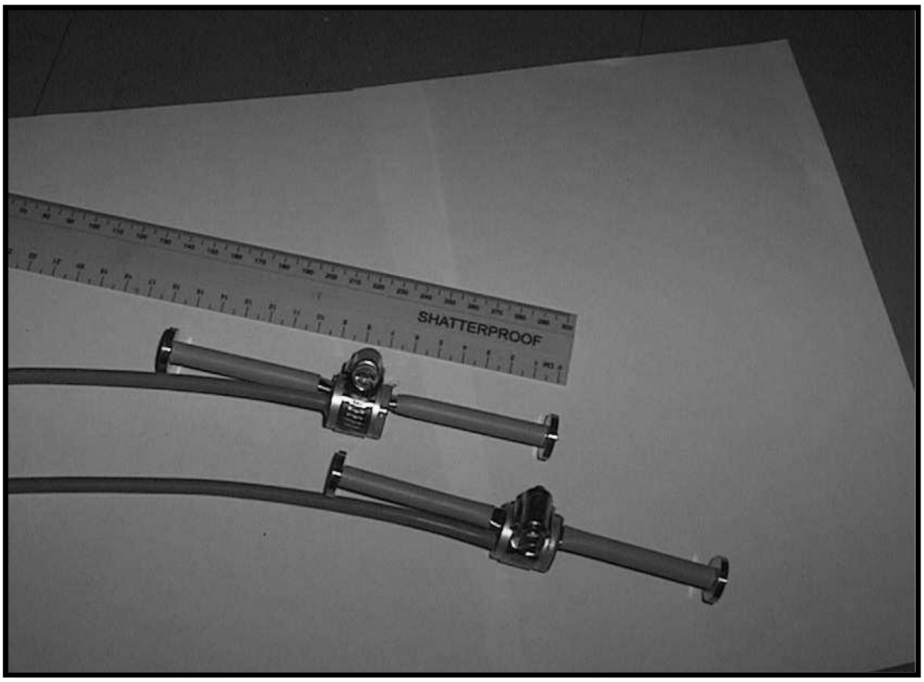

Figure 8
GEOKON vibrating wire strain gauges

Strains are measured using the vibrating wire principle:

- A length of steel wire is tensioned between two end blocks that are embedded directly into the medium.
- Deformations within the medium mass will cause the two end blocks to move relative to one another, thus altering the tension in the steel wire.
- Plucking the wire, and measuring its resonant frequency of vibration, by means of an electromagnetic coil, measures this change in tension.
- The readout box will provide the necessary voltage pulses to pluck the wire and will convert the resulting frequency reading directly into strain units by means of an internal microprocessor.
- The advantage of the vibrating wire over more conventional electrical resistance types lies mainly in the use of a frequency, rather than a voltage, as the output signal from the strain gauge. Frequencies may be transmitted over long cable lengths without appreciable degradation caused by variations in cable resistance, contact resistance or leakage to ground.
- The strain gauges are provided with thermistors encapsulated in the plucking coil. These enable temperatures to be measured as well.

Installation Program and Siting

The strain gauges are installed in a harnessed ring containing 8 monitoring sites (Fig. 9). Each of these 8 sites consists of two strain gauges that are orientated in the vertical and horizontal directions. The cabling from each of the 8 sites is routed circumferentially to a junction box from which the readings can be taken. Nine instrumentation sites were initially highlighted for the Main Shaft and Vent Shaft, of these only eight have been installed in the Main Shaft and nine in the Vent Shaft respectively. The sites were initially selected on the basis of where the largest movements in the concrete or shotcrete, were anticipated to occur. The first instrumentation ring in the concrete section above the shotcrete for the Main shaft was not installed due to a timing mix-up; hence the first ring installed was in the shotcrete section, situated approximately 10m below the concrete shotcrete interface (Fig.10). The first instrumentation ring in the Vent shaft was however installed in the concrete section above the shotcrete situated approximately 10m above the concrete shotcrete interface. As far as the author is aware no such extensive instrumentation program has been undertaken elsewhere on another shaft complex, to date.

It is envisaged that routing cabling from the various junction boxes on each instrumentation site to a common readout unit situated on one level will centralize data logging. The aim is to fully automate the system by transmitting data via leaky feeder, fibre-optics or hard-wired cable to a stand-alone computer situated on surface. The capability of the data logger, recording data at pre-set intervals facilitates this automation process. The instrumentation program will be fully functional as described above by mid 2003, once the commissioning of the shafts has been accomplished.

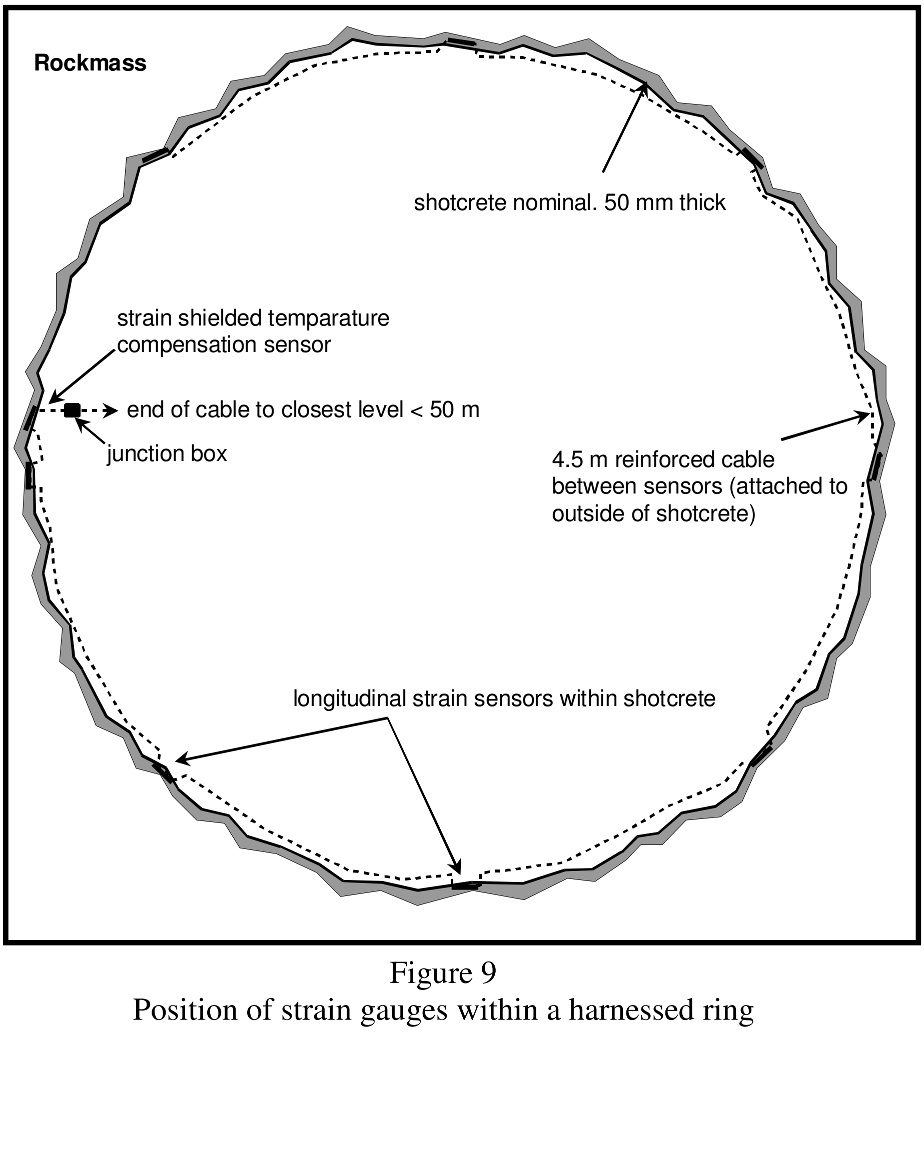

Figure 9
Position of strain gauges within a harnessed ring

To date both the Main and Vent shaft have been instrumented, refer to Tables 7 and 8 below:

Ring	Actual Elevation [m]	Description of Site	Date Installed
A	-2372.9	In Shotcrete lined section	09-04-99
B	-2409.5	In Fargo fault zone	02-05-99
C	-2481.2	In East Arrow fault zone	09-06-99
D	-2525.5	Above VCR stoped out area	01-08-99
E	-2546.7	Below VCR stoped out area	20-08-99
F	-2633.0	Between 94 and 95 level	18-11-99
G	-2709.0	Above 100 level station	11-02-00
H	-2771.0	Below 100 level station in concrete lining	17-02-00

Table 7
Main Shaft Instrumentation Sites

Ring	Actual Elevation [m]	Description of Site	Date Installed
A	-2332.0	In concrete lining above first recess tower	21-12-99
B	-2390.4	In Shotcrete lined section	02-02-00
C	-2432.3	In Fargo fault zone	02-03-00
D	-2484.1	In East Arrow fault zone	04-04-00
E	-2522.5	Above VCR stoped out area	17-05-00
F	-2556.2	Below VCR stoped out area	11-06-00
G	-2633.0	Below 94 and 95 level	27-08-00
H	-2686.0	Above 100 level station	10-10-00
I	-2706.0	Below 100 level station in concrete lining	

Table 8
Vent Shaft Instrumentation Sites

System Calibration

The workability of the system was tested prior to installation by embedding vibrating wire strain gauges in 600mm x 600mm x 100mm panels sprayed with the current shotcrete mix being used, and comparing the results produced by strain gauge monitoring versus conventional laboratory ram testing. Two such panels with four embedded strain gauges were prepared and tested. Figure 13 reflects the results of the calibration analysis for one of the panels. It is apparent from an analysis of Figure 13 that a strong correlation exists between the ram test load-displacement results and that obtained for the strain gauges. This is borne out by the numerous tests, six panels too date have been tested with the embedded strain gauges, the summarized results are presented in Table 9. The confidence achieved in obtaining reliable results from the vibrating wire shaft instrumentation is thus high.

Further panel tests using the vibrating wire strain gauges and comparing the results with those obtained by the conventional hydraulic ram are presently on going. With the exception of the first two sets of results, the failure (first crack) of the panels occurs at values between 0.7 and 1.57 millistrain. Additional compressive strength testing in the form of vibrating wire strain gauges embedded in shotcrete cubes will also be carried out for completeness as well.

Panel	Date	UCS [kN]	Vibrating wire strain [mm/m]	Deformation [mm]
1	04-02-99	146.3	0.07?	13.9
2	30-03-99	70.1	0.15	15.4
3	13-03-00	156.1	1.18	4.3
3	13-03-00	156.1	0.73	4.3
5	13-03-00	143.1	1.25	3.5
5	13-03-00	143.1	0.7	3.5
6	13-03-00	119	1.57	4.6

Table 9
Panel tests with the vibrating wire strain gauges

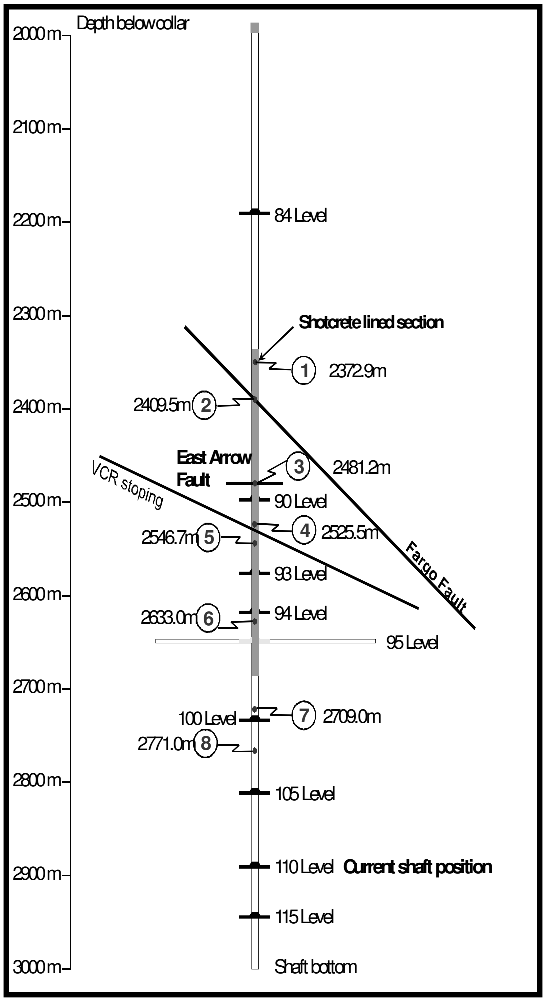

Figure 10
Instrumentation sites along the Main Shaft barrel

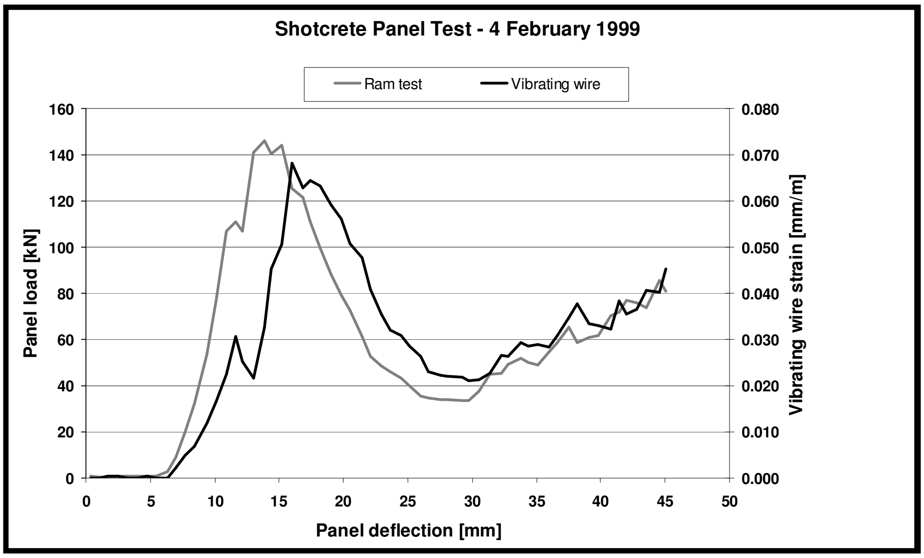

Figure 11
Results of vibrating wire calibration tests

INSTRUMENTATION RESULTS

Results from the installed shaft instrumentation sites are currently being obtained on an ad-hoc basis as and when the sinking shaft schedule allows for it. The initial reading is taken immediately after the instrumentation ring has been installed in the shotcrete or concrete. The zero base reading is then taken approximately 28 days after the installation of the ring, where after readings are taken as described above. During shaft equipping the cabling requirements for the automated reading of the instrumentation sites will be installed. Thus by mid 2003, it is envisaged that all the various sites will be accessible by a computer residing on surface. At present only a limited amount of data is available from the various sites installed, with the majority only having the zero base readings taken. An example from one of the instrumentation rings in the Main Shaft (Ring A) with three readings, is presented in Figures 12 & 13.

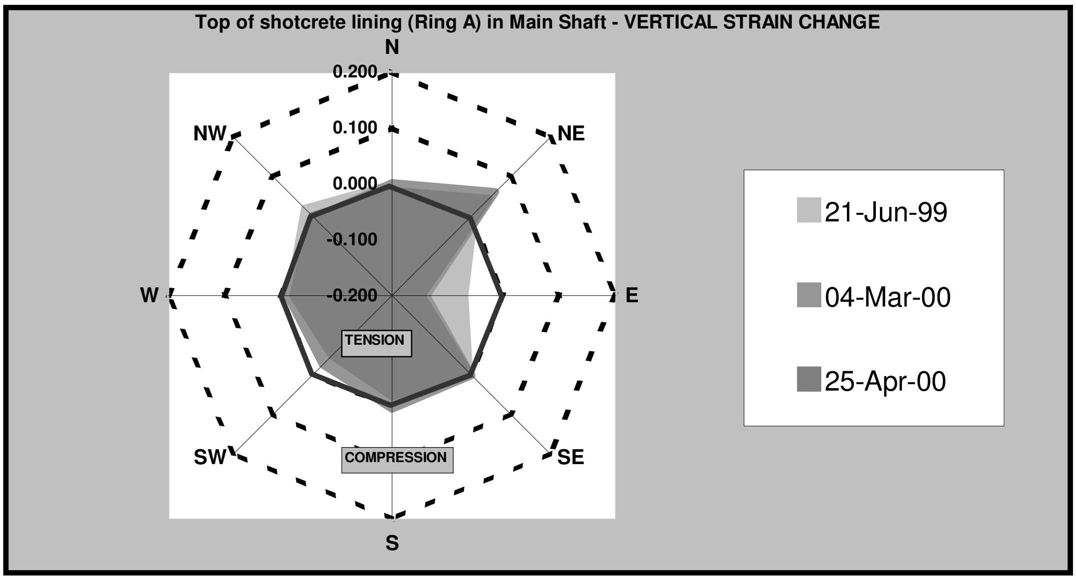

Figure 12
Vertical strain change results for ring A

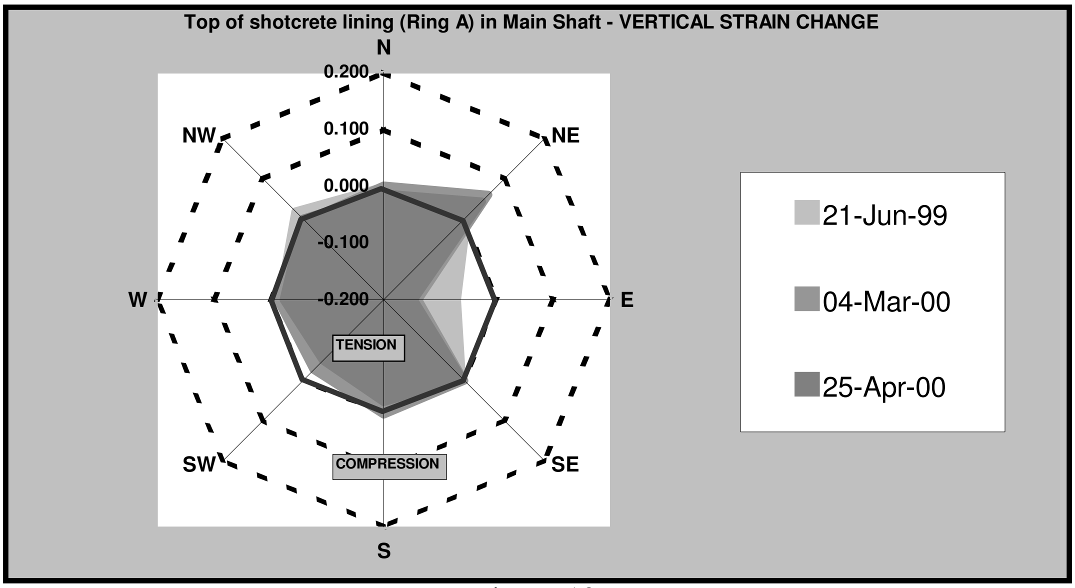

Figure 13
Horizontal strain change results for ring A

What this particular type of plot immediately portrays is an overall (plan) view of the state of strain, both from a spatial (circumferential), and time related change. From the figures it is evident that the vertical strain in the shotcrete indicates slight tensile behaviour, especially in the eastern quadrant, while the horizontal strain exhibits compressive strain behaviour, in the northeast quadrant, in the time since installation. What is also significant is the magnitude of these strain values, the values are all below 0.1 millistrain, and hence no failure of the shotcrete is expected to be occurring in this region of the Main Shaft. Plots like these are generated for all the various rings (vertical and horizontal), for the Main and Vent shafts as part of the routine instrumentation monitoring program. To date none of results from the 17 rings installed indicate any problems.

The next phase of the program will consist of setting up the VCR mining such that the influence of the mining on the rockmass in the shafts can be simulated using numerical models and the results compared with those obtained in-situ, on an ongoing basis.

To date two additional stress measurements have also been undertaken in the Main Shaft, in order to quantify the effect of de-stressing on the shaft system due to the VCR mining above. The first of these results were undertaken on 95 level, where the initial stress measurement for the shaft pillar pre-extraction modelling was carried out in the mid 90's. The recent results on 95 and 100 level confirm that the principal of de-stressing works.

Contour plots of the instrumentation sites for each shaft have also been generated in the past, but due to the distances between the individual rings, the influence of faults on the results, together with the limited number of data points, the validity of the inferences from these plots is questionable.

CONCLUSIONS

The Previous work undertaken by the on-mine shotcrete-working group has been pivotal in the design, production and placement of high quality wetcrete in the South Deep sinking shafts.

Future work will concentrate on calibrating the in-situ measurements with that obtained by numerical methods. Prediction of rock mass instability and support performance can only be scientifically quantified by use of a combination of analytical methods, numerical methods and in-situ analysis. The results of in-situ analysis form a verification tool of initial design and may prompt changes to both analytical and numerical methods of analysis. Scientific design based on either numerical and analytical design methods alone, face the risk of not accurately predicting rock mass characteristics and hence stability requirements. Insight into possible failure modes, early indication of failure and support performance can only be accurately determined if 'backed-up' by suitable in situ analysis.

The present instrumentation program of the South Deep sinking shafts is unique in it's application of embedded vibrating wire strain gauges too monitor the long term performance of the placed wetcrete and concrete. It is believed that the results obtained from the instrumentation will provide valuable insight and stimulate further research into understanding the behaviour of the rockmass in the near field of shaft excavations and the response on protective linings.

ACKNOWLEDGEMENTS

The author wishes to thank the management of the Placer Dome Western Areas Joint Venture and JCI Ltd. for permission to publish this paper. On a sad note, whilst preparing this paper Leon Jiyana who was actively involved in this project passed away, we will forever miss your unbounded enthusiasm. A special thank you is expressed to all that were involved in the South Deep Sinking Project, without whom the project would not have been a success, especially to Trevor Rangasamy, who has moved onto greener pastures for all his hard work, comments and ideas on this paper.

REFERENCES

1. European specification for sprayed concrete. Guidelines for specifiers and contractors, 1999. Hampshire. EFNARC.

2. Erasmus W.P. 1999. Personal communication. Contracts Mining Engineer. J.C.I Projects.

3. Geopractica c.c. 1999. Procedure for quality assurance at the South Deep Site, PDWAJV. Unpublished Internal Report.

4. Leach A.R & Balt K.D. 1999. Examination of shaft lining loading and stability at Western Areas, South Deep. Consultant Report. ITASCA Africa: South Africa.

5. MacDonald A.J. 1998. Design considerations for the extraction of a wide orebody in a South African deep level gold mine. PhD Thesis. Cardiff School of Engineering, University of Wales, Cardiff.

6. Parrish A.J. 1999. Personal communication. Senior Concrete Technologist. Anglo American Technical Services, South Africa.

7. PDWAJV. 1999. Working Procedure, South Deep Section. Internal Publication.

8. Pethö S.Z, Rangasamy T & Raffield M.P. 1998. South Deep Shaft Protection. Unpublished Internal Report.

9. Raffield M.P, James J.V & Pethö S.Z. 1998. Monitoring of the performance of a crushed waste/classified tailings backfill for shaft pillar pre-extraction in the South Deep Section, Western Areas Gold Mine.

10. Raffield M.P, James J.V & Isaac A.K. 1993. Computer modelling of shaft movements induced by the pre-extraction of the shaft reef area on the South Deep Mine. In proceedings Minefill 1993. SAIMM: 65-72.

11. Rangasamy T, Jiyana L, Petho S.Z, 1998 Support design, implementation and monitoring in the South Deep shaft system, Placer Dome Western Areas Joint Venture. In proceedings SARES 99

12. Rangasamy T. 1999. Instrumentation of the South Deep Main shaft using vibrating wire technology. Unpublished Internal Report.

13. Rangasamy T. 1999. Flashcrete requirements for the Main shaft. Unpublished Internal Report.

14. Rock Engineering Department. 1998. Code of practice to combat rockfalls and rockbursts accidents