The rehabilitation of Impala No. 1A ventilation shaft
by A. Bothma*

Introduction
The Impala No. 1A ventilation shaft is located approximately 15 kms north of Rustenburg and is accessed via the R510 road from Rustenburg to Northam/Thabazimbi. This situation is shown on the location plan in Figure 1. The geology at the site consists of an upper layer of black turf of about 1 metre in thickness, grading into weathered norite. The depth of weathering is generally less than 5 metres. Zones of deeper weathering may occur along fracture zones associated with faults and dykes. Groundwater occurs mainly within the weathered/fractured aquifer system.

The ventilation shaft is a 5.1 m diameter upcast shaft, and forms part of a system of ventilation shafts to complement the existing infrastructure as mining progresses down the new twin decline extension of Impala 1 shaft. The principal reason for these shafts is to lessen the risk of an extended RAW and also to counter the effects of the heat build-up as the mining goes deeper, with the resultant effect that the existing cooling centre (fridge plant) becomes more remote from activities.

The No. 1A shaft (upcast) is positioned approximately 1.2 km on down dip from the main shaft and the No. 1B shaft (downcast) approximately 1.2 km further. Geological information was used from a borehole 1.2 km away on strike from the upcast shaft. The first shaft (1A) is a 5.1 m diameter hole to be fitted with two 2.2 MW fans, whilst the second shaft (1B) is 4.1 m diameter to accommodate a 7MW fridge plant.

Background
In October 1998, consultants were called in to investigate the feasibility of pre-cementation to control groundwater inflow into the proposed ventilation shaft No. 1A at Impala Platinum Mine. This was as a result of serious water ingress and loss of circulation encountered whilst drilling a 250 mm pilot hole for the proposed shaft. Volumes of up to 40m³/h were reportedly pumped from the pilot borehole during drilling with very little drawdown resulting.

It had been decided to raise-bore the shafts for economical as well as time-related reasons, specifically as they were both required for ventilation purposes only. The raise-bore chips could then also be handled better and more easily through the existing infrastructure underground.

The objective of the consultants, investigation was to identify the geological features that influenced groundwater flow to the proposed shaft and assess the feasibility of blocking the groundwater movement by pre-cementation.

Four holes ranging in depth from 40 m to 80 m were drilled. These holes were sited at the corners of the concrete block, whilst in addition, the mine drilled 12 holes to facilitate grouting around the pilot hole. The formation underlying the site was found to be highly fractured and weathered particularly in the zone from surface to a depth of about 40 m. Serious problems of hole collapse and loss of circulation were experienced in this zone during drilling. Below 40 m the formation becomes more competent with localized fractures and weathering to a depth of about 60 m. The depth and degree of fracturing and weathering generally increased diagonally across the collar. Cementitious grouting was carried out around the pilot hole to stop loss of drill water circulation and groundwater inflow into the hole. This was carried out in order to facilitate drilling to the target depth of over 1000 m. Grout was injected into the ground through twelve holes within a radius of seven metres round the pilot hole.

The extensive tests carried out confirmed that a detailed hydrological assessment of the conditions would be required together with a proposal for water sealing before the raise-boring could take place. The proposal which was accepted consisted of a series of holes in a circular pattern around the shaft to create a curtain. Differential curtain grouting was effected with Tube-Manchets for additional assessment of sealing, and also to provide the facility to resal again if the need arose. This method was implemented until a fusion value of less than seven was achieved.

The main contractor Rucbor was called back to site to continue with the raise-boring. However, ingress of subsurface water (in the region of 10 litres/second) were still being experienced through the sidewalls as the reamer head ground its way to the surface. It was evident that the sealing of the sidewall had been washed away, causing major falls of ground in the process.

A platform was built to assess the damage to the shaft caused by the rockfalls and also to allow construction of a mini-headgear for possible rehabilitation. A video camera was then lowered to allow viewing of the inside of the shaft and to judge the extent of sidewall damage. This allowed for a more advised decision on the repair of the sidewall.

Rehabilitation proposal
The ventilation shaft had been raise-bored with the concrete collar being installed to approximately 4 metres below ground level, and although designed as an upcast ventilation shaft, the air extraction system currently being utilized underground on the rest of the mine turned the shaft into a...
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downcast shaft. Rock falls if in sufficient quantity or if allowed to build up to such an extent that the shaft became blocked at the bottom, immediately turned the shaft into an upcast situation, with air being forced up at a high velocity.

Rucmin were then contracted to execute the rehabilitation works using a ‘stage’ suspended from four Skyjacks and a cage suspended from two Skyjacks. This equipment was suitable to inspect the shaft to a depth of 100 m, although early indications were that it would only be necessary to go to a depth of 60 m.

The lightweight, single deck stage was suspended in the shaft by means of six ‘Skyjack’ winches attached to the headframe. Ropes of 9 mm diameter were attached to the stage whilst the design of the control circuits was such that the winches could be operated either in unison or individually to enable levelling of the stage. The stage could be raised or lowered at a speed of 6 m per minute. In addition to the ‘live’ ropes, an additional six overspeed ropes were hung from the headframe and passed through the stage. The overspeed ropes ran through brake blocks attached to the stage and were designed to prevent a runaway should the skyjack winches fail for any reason. A service cage was installed for personnel access as well as the possible movement of the materials to the stage. This also ran on ‘Skyjack’ winches with guide rails being installed on brackets at 3 m centres.

Figure 2 shows the small headgear which was constructed to facilitate the rehabilitation work.

Grouting from the surface around the periphery of the shaft had not prevented the ingress of high volumes of subsurface water from penetrating the shaft therefore an alternative approach was decided upon which entailed the following:

➤ Application of a primary shotcrete layer to the shaft substrate

➤ The installation of 3-metre anchor bolts

➤ Subsequently, the introduction of a low pressure grout through the shotcrete to seal the fissures in the rock conveying the water

➤ The application of the final layer of shotcrete.

The shotcrete method proposed was the wet method, with Geopractica employed to provide the critical mix design, mix and pump the shotcrete underground, as well as carry out the QA and QC programmes which were essential for the project. MBT Mining and Tunnelling were consulted with respect to the chemical additives to be incorporated in the mix with specific regard to the wet conditions existing. In addition, they provided the equipment, shotcrete application training as well as the normal back-up service commensurate with the product supply.

Contract methodology

The condition of the shaft was poor due to the deterioration of the rock as a direct result of the water, therefore it was necessary to stabilize the sides of the shaft in the quickest manner, thus reducing the exposure time to the possibility of rock falls. It was agreed that the operations that satisfied these criteria the most were the barring down and washing down of the face followed immediately with the spraying of a fibre-reinforced shotcrete layer of 75 mm, being equivalent to half the total thickness specified.

Once this work had been executed the installation of anchor bolts would follow, thus enhancing the stability of the shaft. On completion of the anchor bolts, the safety in the shaft was considered suitable for the relatively slow procedure of drilling and grouting to seal the fissures conveying the water.

After completion of these operations to an agreed position, where water ingress was negligible or considerably reduced, the second shotcrete layer, making up the total thickness was applied. This second layer covered the anchor bolt heads to protect them from erosion.

The application of the primary layer of shotcrete proceeding downwards from the collar resulted in the pressure of the sub-surface water increasing to such an extent that channelling of the water away from the surface to be sprayed was required.

This contract methodology was agreed upon by the parties concerned. However, due to the prevailing conditions, certain amendments or ‘fine tuning’ would almost certainly be required as the work progressed.
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Mix requirements/design

It was decided at the commencement of discussions that due to the shaft conditions and the limiting parameters, the wet shotcrete process would be used. This process would give a constant water/cement ratio which would also allow a controlled quality mix. This was essential in these conditions. Due to the controlled mix, improved bonding to the substrate as well as higher compressive strengths could be achieved with very little variation to results.

The wet shotcrete process also lends itself to the use of new admixture technologies which would then allow the 75 mm layer thickness to be applied in a single pass without any problem.

The shotcrete design had to comply with the following parameters:

- Compressive strength (cubes) minimum 50 MPa
- In situ compressive strength (cores) minimum 30 MPa
- Energy absorption minimum 700 Joules
- The mix design must incorporate 40 mm minimum length polypropylene fibre
- The mix must be eminently pumpable
- The mix must be capable of being sprayed in wet conditions.

An additional requirement of the mine was that the work must commence within two weeks.

These specifications and conditions required that a proven mix design be used, as insufficient time existed to carry out a mix design with locally available materials. At that stage all shotcreting being carried out locally was by the dry process, and no performance data for any of these mixes was available. Owing to these reasons, it was decided to use a shotcrete base mix design similar to that which was currently in use at South Deep Mine.

The original mix design for South Deep Mine incorporated steel fibre and was developed by Mr A. Parrish, then of Anglo American Technical Services, to accommodate conditions similar to those existing at Impala, being:

- Ingress of high volumes of sub-surface water
- Reduced permeability
- High bond strength with substrate
- High tensile strength
- High energy absorption values.

The base mix affects the tensile strength and energy absorption however, the type and quantity of fibre has by far the greatest influence on these characteristics. A fibre satisfying these parameters had to be selected for incorporation with this design.

It was decided that the mix characteristics were suitable to pump and spray a 50 mm monofilament polypropylene fibre, over the distances required (± 80 m) which was another reason for the selection of the base mix. Practical tests were carried out at MBT’s premises to ensure that the expected pumpability could be satisfied. Minor modifications were made to the base mix as a result of these trials.

Shotcrete mix design

<table>
<thead>
<tr>
<th>Description</th>
<th>Quantity per cubic metre</th>
</tr>
</thead>
<tbody>
<tr>
<td>6.7 mm stone</td>
<td>262 kg</td>
</tr>
<tr>
<td>Crusher sand</td>
<td>1080 kg</td>
</tr>
<tr>
<td>Plaster sand</td>
<td>160 kg</td>
</tr>
<tr>
<td>Cem 1 52,5 Cement</td>
<td>475 kg</td>
</tr>
<tr>
<td>Condensed silica fume</td>
<td>38 kg</td>
</tr>
<tr>
<td>Super pozz (micro fine fly ash)</td>
<td>75 kg</td>
</tr>
<tr>
<td>Superplasticizer (Glenium 51)</td>
<td>4.20 litres</td>
</tr>
<tr>
<td>Stabilizer (Delvocrete)</td>
<td>3.64 litres</td>
</tr>
<tr>
<td>Internal curing agent (Meyco TCC 735)</td>
<td>5.60 litres</td>
</tr>
<tr>
<td>Accelerator (Meyco SA 160)</td>
<td>Varies</td>
</tr>
<tr>
<td>Micro fibre</td>
<td>0.91 kg</td>
</tr>
<tr>
<td>50 mm monofilament polypropylene fibre</td>
<td>7.5 kg</td>
</tr>
<tr>
<td>Total water</td>
<td>200</td>
</tr>
<tr>
<td>Water/Cement Ratio</td>
<td>0.34</td>
</tr>
<tr>
<td>Flow</td>
<td>550–600 mm</td>
</tr>
</tbody>
</table>

It should be noted that the design strength of this mix was higher than required, however, with the large quantities of sub-surface water encountered on the substrate, high accelerator dosages were required to accelerate the mix. The accelerator also contains approximately 60% water. The combination of the above two additional sources of water has a serious impact on the water/cement ratio of the mixed shotcrete, reducing the compressive strength considerably.

Materials for the shotcrete

The materials used were as detailed below and delivered in the manner described.

Aggregate

The aggregate mix was factory blended as per the mix design and delivered in bags with a mass of approximately 23 kg. This translated to 75 sacks of aggregate per cubic metre of shotcrete.

Cementitious material

The cementitious material comprising of cement, condensed silica fume and super pozz were pre-blended by mass and delivered in bags containing approximately 23 kg. Twenty-five bags of cementitious material were required to manufacture 1 m³ of shotcrete.

Fibre

The monofilament polypropylene fibre specified is manufactured from high performance polymer and specifically shaped to resist matrix pull out. The non-corrosive characteristics was obviously one of the main reasons for the specification, whilst the 50 mm length gave the required energy absorption characteristics. The fibres were delivered in boxes containing 9 kg and the specified batch mass was weighed out on site. The microfibre was premixed into the bags containing the aggregate at the required ratio.

Additives

All additives were delivered to site in 220 litre drums enabling the required quantities to be tapped off accordingly. The following additives were used which considerably enhanced the mix performance and certainly contributed to both the application and quality of the final product:

- **Superplasticizer (Glenium 51)**—This was used to give the required consistency for spraying and to aid pumpability as well as allowing significant water reduction and hence a higher compressive strength.
- **Stabiliser (Delvocrete)**—This product is a hydration control admixture which maintains the workability of the mix and extends the open time during transportation and application without reducing concrete quality. In this instance where 50 mm diameter steel pipes were used down the shaft and the total pumping distance varied to over 80 m, this product was invaluable.
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- **Internal Curing Agent (Meyco TCC 735)**—This is a particular admixture added to sprayed concrete to improve the bond with the substrate as well as to assist the curing cycle of concrete where traditional curing methods cannot be used.
- **Accelerator (Meyco SA 160)**—This is an alkali-free accelerator which improves concrete durability and allows the spraying of large thicknesses in a single pass. The dosage can be adjusted to ensure good cohesion between layers.

**Equipment selection**

Enquiries revealed that no Ready Mix concrete suppliers had wet mixing facilities in the area. Furthermore, experience has shown that the mixing of shotcrete in a Ready Mix truck is unacceptable as insufficient shear is imparted to the mix. This in turn increases the quantity of water incorporated in the mix for a given flow. Based on these facts the supply of premixed shotcrete from commercial sources in the area was eliminated.

As the conditions dictated that the shotcrete had to be applied by the wet process, it was necessary to mix the shotcrete at the mine on surface, and pump the material up to 70 metres underground. The capacity of the stage was insufficient to accommodate anything more than the labour, accelerator pump, accelerator as well as small tools and equipment.

The equipment selection made was a V300 Pan mixer (200 litre yield wet) together with a Coretta positive displacement pump which was capable of pumping the required distance as well as at the required rate. The two units were matched in terms of the output of the mixer into the hopper of the pump with a suitable loading platform constructed to enable productive loading of the mixer (see Figures 3 and 4).

Communications between the nozzle operator on the stage and the mixer and pump operators were via phone and signal bells. In order to transport the concrete from the pump to the area of application down the shaft, a combination of 50 mm diameter steel pipes and flexible delivery and spraying hoses were used. The brackets on the guide rails fixed in the shaft also supported the cables, air and water reticulation as well as the 50 mm diameter steel pipe line for the shotcrete.

**Shotcrete operation**

This section will cover the basic work programme, the initial preparation of the substrate prior to spraying, the mixing and pumping of the shotcrete as well as the application procedures.

**Work programme**

The original programme for the work dictated that two shifts would have to be worked to tie in with the overall work programme. The works were commenced in the middle of winter, and this combined with the fact that the shaft was sucking air down, caused the sub-surface water to freeze on the substrate resulting in all night work having to be abandoned. (Temperature of -9° centigrade).

In addition to the freezing of the water in the shaft, the chemicals used in the shotcrete mix required that they be kept at a minimum of 5°C, thus restricting the time available for mixing. Water for the mixing was supplied from a borehole and stored in a tank which gravity fed the mixer. The water also froze in the storage tank overnight which affected the time that mixing could commence. A combination of the above facts dictated the period of mixing daily.

The temperature conditions also meant that personnel had to be equipped with special cold weather gear, whilst the lubrication oil for the rockdrills had to be kept in the concrete cube bath to prevent the rockdrills freezing.

**Preparation of substrate**

The substrate was first prepared by the barring of loose rock and cleaning with water at high pressure where required. This operation was not easily executed, as the barring off of any loose rock had to be carried out below the bottom of the stage to prevent a rock fall onto the stage.

As the first shotcrete layer progressed downwards the pressure of the sub-surface water increased considerably, necessitating the following measures.

- Installation of kerb rings to cut off sub-surface water flowing down the face of the substrate. The kerb ring was made up out of sheet metal and bent to the shape required forming a gutter. This ring terminated with a rubber pipe draining the water collected, away from the substrate to be sprayed.
- Introduction of pipes into fissures where the flow of water was concentrated in order to divert the water from the substrate. This was carried out by drilling into the fissures and inserting 25 mm diameter rubber hose...
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pipes. The hose pipes were held in place by a cementitious product that sets quickly in the presence of water.
- Other areas required the sealing off of water altogether, which was effected by the application of a similar product to that previously stated. This could only be executed where the water pressure was low.

Mixing of the shotcrete

The materials were combined and mixed in a 300 litre dry 200 litre wet, pan mixer that was located adjacent to a Coretta positive placement pump, in such a manner that the mixed shotcrete was discharged directly into the pump hopper. The size of the pump hopper was increased to accommodate two batches of mixed shotcrete with a third batch being mixed and held in the mixer ready for discharge. This allowed for the continuous spraying of just over a half cubic metre of shotcrete at a time.

This factor was quite important as the accelerator dosage rate did not have to be continually adjusted during each spray session and the nozzle operator could spray sufficient material to get into a routine without becoming overtired.

The mixing of the shotcrete was carried out in the following sequence of additions to the mixer:
- Aggregate
- Micro fibre
- Cementitious material
- Water
- Chemical stabilizer and superplasticizer once a quarter of the total water had been added
- Internal curing agent
- Polypropylene fibre
- Water to adjust the flow if required.

Pumping of the shotcrete

Prior to the shotcrete being pumped, the pipe from the pump to the nozzle was generously filled with cementitious slurry, the texture of which being similar to thick cream. This slurry lubricates the pipes and assists with the prevention of blockages. The shotcrete was pumped first through 10 m of 50 mm diameter flexible pipe and then through a 50 mm diameter steel pipe fixed to the side of the shaft down to approximately 10–15 m above the area being sprayed and then once more by ± 25 m of flexible hose to the nozzle.

The selection of pipe diameter was important, as the shotcrete was required to move not under its own mass, but rather by pumping pressure. Once the shotcrete was being pumped to reasonable depths, at the commencement of each spraying cycle, the flexible pipes attached to the end of the steel pipe were only added once the shotcrete was pushed through. This was to assist with the prevention of blockages, and to identify where a blockage was, should one occur. The steel pipes were progressively stripped out as the second layer of shotcrete proceeded to be installed from the bottom of the lined portion of the shaft upwards.

Spraying procedures

Accelerator was added at the nozzle from a small container on the stage via a Mono Pump. The container on the stage was filled at regular intervals by pumping down accelerator from the bulk storage drum on the surface, via a small air pump and plastic pipe. This method of accelerator addition gave the nozzle operator full control over the rate of addition of the accelerator. This is of particular importance when spraying in very wet conditions. Spraying was carried out in the standard manner of a small circular motion of the nozzle with the shotcrete being built up to the required thickness. (See Figure 5).

Training

Training of personnel was a critical aspect of the complete operation. Fully trained personnel were used for the mixing operation with a full understanding of the order of addition of materials and chemicals. Geopractica had full time mixing as well as quality assurance personnel during the contract to ensure the overall quality of the final product. This was a major contributing factor in the success of the contract.

Nozzle training was of particular importance and this was carried out in conjunction with MBT Mining and Tunnelling who also provided on-site coaching and assistance. Special spraying services were supplied by MBT where conditions warranted. The final quality of the shotcrete lining as depicted in Figures 6 and 7 is a testament to the quality application of the shotcrete.

Drilling and installation of anchor bolts

After the first layer of shotcrete had been sprayed and sufficient substrate had been stabilized to give safe working conditions, anchor bolting was commenced. In the area from surface to a depth of 35 metres, no falls of ground were experienced, therefore 3 metre swellex bolts were deemed to be sufficient. The bolts were installed in a 1 metre square pattern with 15 bolts per linear metre. Due to the ground conditions encountered, only 30 holes were drilled per 12 hour shift. An additional factor that contributed to the relatively slow rate of progress was the old poly grout in the water-bearing fissures which continually blocked the water tubes of the drill steels.

As a result of the highly fractured nature of the rock between 35 metres and 70 metres as well as several falls of ground, it was deemed necessary to install 3 metre full column resin grouted anchors. These were installed according to a similar pattern as the swellex bolts.

Sealing of rock fissures

To enable the application of shotcrete to commence, the fissure water needed to be either sealed or channelled. This was done by either drilling holes to intersect the water and installing telescopic pipes or by using a grout that sets rapidly in the presence of water.

Figure—Shotcrete spraying from stage

| ➤ Water to adjust the flow if required. |
| ➤ Cementitious material |
| ➤ Micro fibre |
| ➤ Aggregate |

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The pipes were installed to divert the water from the substrate, thus enabling the first layer of shotcrete to be applied. On completion of the first layer, grout was injected through the pipes, sealing the water-bearing fissure and the pipe itself. This enabled the second layer of shotcrete to be applied. As the grouting of the fissures progressed downwards, the water pressure increased accordingly requiring more extensive grouting to be undertaken with lower degrees of success. This fact affected the application of the shotcrete as the depth at which the work was being executed increased.

Quality assurance and quality control

Quality assurance

Quality assurance was carried out on both the mixing and application of the shotcrete with the following checks and tests being executed:

At the mixer

- Random duplication of the counting of bags added to the mixer, both aggregate and cement
- Random checking of fibre mass addition
- Random checking of chemical volume addition
- Regular flow tests being taken on the mixed shotcrete
- Cleanliness of plant and equipment
- Observation of the mixing process by senior staff on a regular basis
- Observations by the Contractor’s senior personnel on site
- Visits by the Mine’s management
- Regular checks on air pressure when spraying shotcrete.

Underground

- Cleanliness of equipment with nozzles being stripped and cleaned daily
- Thickness tests being taken continually during spraying to determine if the required thickness had been applied
- Observation of the nozzle distance from the substrate whilst spraying
- Observation of the angle of the nozzle to the substrate whilst spraying
- Accelerator addition
- Mix temperature
- Blockages and the reasons therefore.

It should be noted that the observations were treated proactively with corrective actions being implemented immediately.

Quality control testing

The following regime of control testing was implemented:

- Compressive strengths (cubes): 6 daily
- Compressive strength (cores): at commencement of work
- Energy absorption: every 20m

EFNARC panels could not be sprayed on the stage due to the additional mass these panels imposed. Pumping pipes, accelerator pump, accelerator containers and piping had to be removed from the shaft and stage to carry out the spraying of control panels on the surface.

Conclusions

The successful completion of the rehabilitation of Impala No. 1A ventilation shaft was undoubtedly due to a combination of good planning, effective communication, quality materials and work standards, as well as good maintenance and service support. The total team involved in the project, i.e.: Impala Platinum Mines, RUC, Geopractica and MBT responded in a positive way despite what seemed like impossibly adverse conditions at times.

This paper has reviewed how the fall of ground incidents and water seepage problems were dealt with and the critical importance of the wet shotcrete process within the final solution. Key aspects of the overall contract which can be reiterated were:

- Constant on-the-job training to suit the changing conditions in the shaft
- Quality assurance programmes that ensured that the specifications were met and generally exceeded
- High work standards on the project resulted in no accidents for the 7-month duration
- Proper maintenance of all equipment—minimizing downtime
- Use of industry-recognised quality additives ensuring a quality mix which could be sprayed in the adverse conditions encountered.

In order for similar projects to be addressed elsewhere in South Africa, the principles involved in this project would be recommended. It is amazing the results that can be achieved by a team working towards a common goal and looking for solutions to problems together, instead of finding reasons why a task cannot be completed.

Acknowledgements

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