In-service monitoring of water barrier project at South Deep Gold Mine

by L.J. Olivier*, A.H. Swart†, and C.O. Brawner‡

Synopsis

The possible closure and subsequent flooding of South Deep Gold Mine's (SD) neighbouring Randfontein Estates Limited No. 4 Shaft (REL 4) necessitated the construction of five concrete plugs in the connecting tunnels to prevent the ingress of groundwater into REL 4 from flooding SD. This paper describes the proposed controlled flooding of REL 4, the planned in-service monitoring of the five plugs and the water barrier between REL 4 and South Deep Mine, and the long-term maintenance of the plugs and rock mass in the immediate vicinity of the plugs.

Introduction

South Deep Gold Mine is connected to the neighbouring Randfontein Estates Limited No. 4 Shaft (REL 4) via five underground tunnels, two on 50 level and three on 58 Level (Figure 1). REL 4 is currently required to pump up to 75 megalitres (Mℓ) of water to prevent flooding of the mine. The possible closure of REL 4 necessitated the construction of five concrete plugs in the connecting tunnels to prevent the current ingress of groundwater into REL 4 from flooding South Deep.

This paper describes the proposed controlled flooding of REL 4, the planned in-service monitoring of the five plugs and the water barrier between REL 4 and South Deep mine and the long-term maintenance of the plugs and rock mass in the immediate vicinity of the plugs. The type of instrumentation, locations, frequency of monitoring, assessment of results, procedures for communication of results to relevant parties and appropriate precautionary or remedial actions, where needed, are also discussed.

Proposed flooding of Randfontein Estates Limited No. 4 Shaft (REL 4)

Boundary pillar competence

Despite the fact that all precautions have been taken to prove that the boundary pillar between REL No 4 Shaft and South Deep is intact, it is still possible that there might be holings, man-made or otherwise, and therefore the only way to prove its water tightness is to flood REL No. 4 S/V Shaft in a controlled fashion.

Flooding rate

The envisaged flooding rate is 50 megalitres of water per day and should take approximately 90 days to flood up to but below the 50a Level pump chamber level, so as to not endanger that pump station, which is crucial to keep the REL No. 4 Main Shaft dry.

Source of floodwater

The flooding is to take place from REL No. 4 Shaft's upper two pump chambers, namely at 33 and 41 levels, including the water reporting naturally to REL No. SV4 Shaft. Water is to be manually redirected from these upper two pump stations to allow it to bypass 50a Pump Station and enter the workings which lead down to 58 level. This redirection of water is to be carried out in such a manner that it can be reverted at short notice should the water level in No. SV4 Shaft need to be maintained or lowered.

Means of controlling the SV 4 Shaft floodwater

In order to maintain or reduce the water level within the SV4 Shaft area during the flooding process, the discharge of water from the upper two pump chambers into the workings would have to cease. High-pressure piping and valving has been incorporated into the 58 West 1 plug to allow controlled drainage of the water contained behind the plugs (Figure 2).

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* *Placer Dome Western Areas Joint Venture.*
† *SRK Consulting*
‡ *International Review Panel*

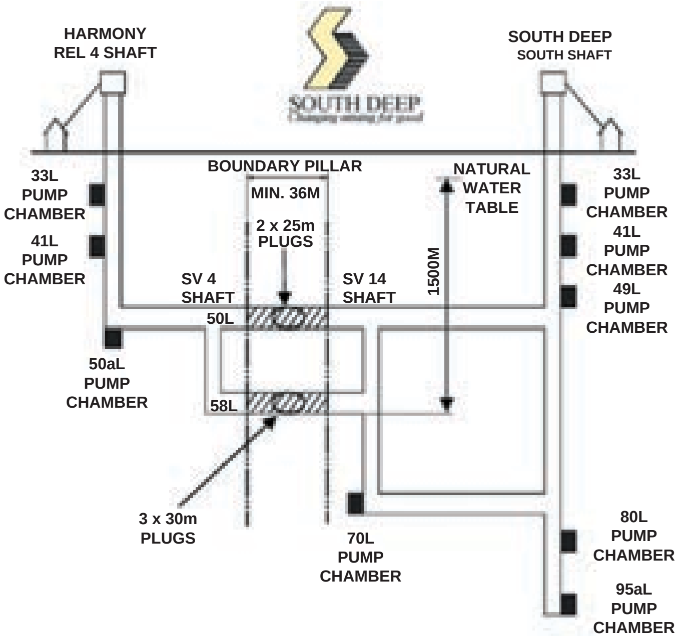

Figure 1—Schematic representation of underground water plug locations

The water level within the SV4 Shaft workings can either be maintained or lowered by varying the discharge flow rate. The water discharged from the plug drainage system would be catered for by the 70 Level pump chamber for disposal to surface via the South Shaft pumping circuit.

It must be kept in mind that this water is heavily contaminated and would first have to be cleaned and chemically treated before being pumped and, secondly, that the 70 level pump station has a limited settling and pumping capacity.

Flooding of REL No. 4 Shaft

Once the controlled flooding of SV4 Shaft reaches the predetermined level the decision to flood REL 4 Shaft can be made. Should the decision be made not to flood the main shaft then the water level within the SV4 Shaft working can be either maintained or lowered, thus proving the competence of the boundary pillar and restoring the emergency water reservoir below 50 Level.

In order to flood the REL Main Shaft the machinery serving the SV4 Shaft will have to be salvaged as with the Main Shaft pumping equipment.

The loss of this 50a pump station, either by choice or accident, is commonly referred to as the point of no return because of the amount of water it handles (settling and pumping) and the head the water has to be lifted to the next stage of pumping (41 Level).

In an emergency the water level in the Main Shaft can be controlled or even lowered by installing high head submersible pumps into the shaft barrel to pump water up the next pump station and by draining water from the 58 level plug system.

These high head submersible pumps are not readily available and would have to be outsourced. This is an enormous undertaking from a practical and financial perspective and would not be considered lightly.

Concepts of long-term monitoring

Monitoring of seepage conditions is envisaged in three phases, namely during:

- controlled flooding up to 50 Level (Phase A)
- recharge of the Gemsbokfontein compartment (Phase B); and
- long-term service under a permanent head of water (Phase C).

As a general principal, while the external factors are changing, e.g. during controlled flooding or natural recharge (Phases A and B), the rate of monitoring of pressure and any groundwater seepage should be frequent (at least at eight hour intervals), so that the source and time of any observed event can be diagnosed accurately and its significance assessed.

Irrespective of the form of monitoring programme that is implemented at any time, records of the factual results, preferably accompanied by cumulative tables or graphs, should be forwarded in 24 hours of the readings being taken in the mine or water quality results being received from the laboratory. Within the mine management team, a designated person should be responsible for receiving and analysing the resulted, and recording the assessment with actions, as appropriate. The parties that are to be kept informed of results and/or assessments are a matter for decision by the

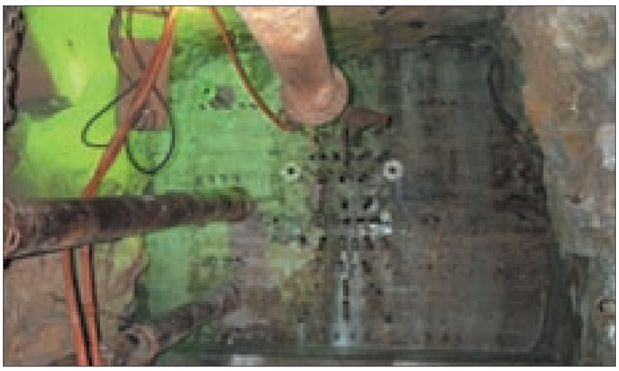

Figure 2—Dry-end of 58 West 1 plug showing 150 mm nominal bore high pressure stainless steel pipes

Placer Dome Western Areas Joint Venture (PDWAJV), as will be the option of involving the International Review Panel (IRP) again.

Access

In the event of flooding of the adjacent REL No. 4 Shaft, safe permanent access to the dry side of all plugs (including force and exhaust ventilation and lighting) should be maintained to facilitate:

- monitoring and recording of any seepage downstream of the permanent plugs in service
- monitoring, maintaining and replacing valves and pressure gauges, as appropriate
- grout infilling and sealing of stainless steel drainage pipes if required
- grouting to improve water tightness of surrounding rock mass, if required.

Prevention of flooding at dry end of plug faces

Water retaining walls (dwarf doors) are to be constructed approximately 30 m from the faces of the plugs in the 50 West and 58 West 1 haulages. These walls should reduce the potential for flooding at the plug faces, in the event of contaminated water and sludge column ingress in the tunnels. By removing the planks, dwarf doors will allow access for rolling stock to the controlled area, in order to load and remove any spillage that might have overflowed.

Dewatering pumps equipped with stop/start level probes should be installed at the retaining walls.

Overall water seepage

The overall water seepage should be monitored on levels 53, 56 and 58 via low wall 'V' notch weirs across the roadways with electronic monitoring of any water flowing across the weirs. Monitoring should be hourly during Phases A and B with eight hourly physical inspections to double check the electronic readouts.

If during the controlled flooding of Phase A, there is a sudden and significant increase in the overall seepage rate, the water level should be recorded and the potential source investigated.

In the event that the overall increase in seepage rate exceeds 2 megalitres/ day (or the trend of increasing seepage within increasing head indicates that 2 megalitres/day will be exceeded), then the water level should be reduced and remedial grouting considered, in order to improve the water tightness of permeable features.

The frequency of monitoring may be relaxed to daily when the hydrostatic head has stabilized and if there is no significant change in seepage rates. As a principle, all reading should be checked in the event of any change in the external factors, e.g. after local seismic activity, when the frequency of monitoring may be increased, particularly if seepage rates have also increased.

Plug inspections

All plugs should be monitored by a designated competent person on a monthly basis. Abnormalities, if any (e.g. water seepage, cracks or fractures in the rock), should be recorded in terms of magnitude and location, in an appropriate mine document and reported to the designated responsible person. Photographs of problem areas to be taken and recorded to monitor deterioration (if any).

Water seepage through drain holes located at the dry side of each plug

Three drain holes (3 m long and fitted with short stand pipes at entry) have been drilled into the side walls (1 off in each at 1° inclination) and hangingwall (1 off) and located about 1m away from the dry side of each plug face. Where appropriate, the holes have been located to intersect known discontinuities immediately beyond the dry end of the plugs.

During service, the monitoring programme for these drain holes should include water seepage rate, water sampling and water quality assessment, e.g. total dissolved solids (TDS). TDS is the total of the suspensions of solid particles and dissolved chemical components in the water and must be measured and analysed.

Samples analysis of TDS at regular intervals determines the type of solids (if any) and whether the rate of corrosion from fault/joint infill materials is increasing or not. If such results are assessed in conjunction with increasing seepage rates, it will help determine the cause and likely source of the flows developing through the rock mass immediately surrounding the plugs that may require treatment by grouting.

A chemical analysis (e.g. redox potential, pH, dissolved oxygen, total alkalinity, Na, Cl, Fe and SO_4) of the seepage water at regular intervals will assist in determining water quality changes with time.

Analysis of pH, acidity, dissolved oxygen, total alkalinity, Na and Cl helps to determine the chemical erosion potential of cement-based products. Fe_{total} and SO_4 contents help determine sulphide (specifically pyrite) reaction rates with the mine water.

Acidity is the total effect of hydrogen ion acidity, weak acids such as carbonic, acetic acids and hydrolyzing salts such as iron or aluminium sulphates. Acidity is determined by titration to pH 8.3.

Total alkalinity (M_Alk) is the total effect of $CaCO_3$, $Ca(HCO_3)_2$, $Fe(OH)_3$ and other materials such as phosphates and silicates. Alkalinity is determined by titration of acid to pH 4.5.

Note. water samples have to be tested in the laboratory and the procedures used in South Africa are described in American Public Health Association, American Water Wastes Association and Water Environment Federation (1998) 'Standard methods for the examination of water and waste' (20th edition).

If water seepage is observed at the downstream drain holes, water flow rates should be monitored every eight hours during Phases A and B. Water sampling and water quality analysis should be carried out initially at monthly intervals.

In the event that no significant changes in water quality are being monitored, and there are no significant increases in water seepage rates, this frequency can be reduced to quarterly.

Under stable conditions, e.g. when the head of water on the plugs is constant and seepage, if any, is not considered significant, the frequency of water seepage readings can be reduced to monthly, bearing in mind that any significant change in overall water seepage will be monitored continuously in real time via the 'V' notch weirs.

If the water seepage exceeds 200 litres/minute (or the trend of increasing seepage with increasing head indicates that 200 litres/minute will be exceeded), then grouting of the leakage zone should be considered.

If grouting around the plug is deemed appropriate as a contingency or remedial measure during service, the drain holes should be used to monitor and measure the effectiveness of the grouting works.

Piezometer readings

Piezometers located at the cold joints within each plug (Figure 3) should be monitored and recorded as soon as the plugs are subjected to a head of water. In such circumstances, when the head of water is rising these readings should be taken daily until the hydrostatic head has reached its final level. Under stable conditions, the frequency of readings can be reduced to monthly, in the event that no significant pressure changes are being monitored.

Aside from permitting pressure measurements within each plug, the piezometer pipes can also be used for grout tightening of cold joints, if required, after which the pipes can be redrilled for ongoing use as piezometers.

Proposed geophone installation

A geophone should be located within the heart of the boundary pillar at 58 Level, so that mining-induced or natural seismic events can be monitored routinely. After a significant seismic event, all seepage and pressure readings should be checked in order to ascertain if any sudden change in reading has occurred.

Records and communication

All observations and measures in the field should be recorded and signed off by a designated responsible person who understands the nature, objectives and significance of the overall monitoring programme. For ease of assessment, the results should be tabulated (or plotted) against time so that trends or changes can be easily observed.

Copies of all results should be forwarded within 24 hours to management where the designated person with knowledge to appreciate the significance of the results, should analyse and assess the results, and take action, if required.

It is also important that the responsible person for taking readings and recording the results should have direct access to Management for immediate reporting and decision making, in the event that any significant change in circumstances is observed during the monitoring programme.

Long-term maintenance during service

Residual permeability checks

Selective residual permeability checks of the rock/concrete interface and the rock immediately surrounding the plug should be carried out annually via a single ring of existing tightening holes (8 off) in the last segment of each plug.

Figure 3—Dry end of plug showing three piezometer pipes

For each tightening hole, drilling should proceed initially until approximately 100 mm of rock mass is intersected. Water pressure testing should then be carried out to establish the residual Lugeon value of the rock/concrete interface and the rock mass.

Sequence of permeability testing

Bearing in mind that there are four rings of tightening holes in the last segments, drilling and permeability testing should proceed in the first year with the inner ring and then work progressively outward towards the fourth and last ring in Year 4.

Over a four-year period, the fourth segment will have been completely checked, after which the whole sequence should be repeated.

Acceptance criteria for residual permeability

The residual permeability of the rock/concrete interface or the rock mass directly surrounding the plug (≤2 m radial distance from plug perimeter) should be 1 Lugeon or less.

1 Lugeon = 1 litre per metre of borehole per minute at an excess head of 1MPa (10 bar)

Supplementary grouting

Where a rock/concrete interface or stage Lugeon value greater than 1 is measured, the hole should be grouted, in accordance with the tightening procedure as prescribed in the general method statement revision 8

After supplementary grouting of the interface and rock mass beyond the interface, the permeability should be re-measured, and if necessary the hole should be regrouted (and retested) until a residual permeability of ≤1 Lugeon is confirmed.

Where the residual permeability is 1 Lugeon or less, the hole needs only to be filled with as thick a grout as possible (e.g. water/cement ratio = 0.4 by mass) at an injection pressure of up to 25 MPa.

Remedial grouting

If during service, water seepage is observed at the rock/plug interface or through fractures in the rock mass immediately surrounding the plug, then all four rings of tightening holes should be drilled, water-pressure tested (Lugeon method) and grouted in accordance with the general method statement revision 8.

In these circumstances, the purpose of grouting all four rings of tightening holes is to provide an engineered thickness of grout treatment over both the rock/plug interface and the surrounding rock mass adjacent of the last segment of the plug.

In the event that the observed seepage is more remote from the plug, then depending on its magnitude and location, fissure grouting of the rock may be considered to form a grout curtain and thereby reduce the permeability of the grout rock mass.

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