Operations for Protection Against Water in Deep Mines

By W.F. HEINZ[1]

[1]RODIO S.A.
P.O. Box 714, Midrand, 1685, Republic of South Africa

ABSTRACT

The extraordinary hydrological conditions in the deep mines in the Southern African region including Namibia, have resulted in the development of grouting and drilling techniques to cope with these often hazardous and difficult conditions. Several gold mines are overlain by waterbearing formations such as dolomites with almost unlimited water storing capacity. Specific techniques in some cases unique to the Southern African mining industry that have been utilised successfully include the following:

- The dewatering of entire "compartments" i.e. areas of several square kilometers enclosed by near impervious dykes, faults, etc., to enable mining activities to proceed under these "compartments".
- The conveyance of cement and other slurries for cement injection and support systems over many kilometers. Underground relay stations facilitate cement injection at practically any distance from the shaft and at any depth.
- The development of robust high pressure plunger pumps. Electro-hydraulic and air-driven plunger pumps capable of achieving pressures up to 50MPa are universally used.
- Drilling techniques have been developed to facilitate safe drilling and grouting against high water pressures.
- The precementation of deep shafts (over 2000m) has been applied successfully to overcome difficult hydrological conditions during the initial development of the mines.
- Special methods to install plugs underground and in flooded mines from surface have been developed and applied successfully.
- Besides the normal cover drilling and grouting techniques special techniques to limit water ingress into shafts and other underground chambers have been developed.

This paper discusses the processes described above and presents various cases where these techniques have been applied successfully.

INTRODUCTION

Mining operations create extensive drainage systems, therefore, water control is an integral part of the mining operations possibly even more critical in the deep mines operated in the Republic of South Africa than elsewhere.

The depth of mine workings ranges from 500m to beyond 4000m from surface, the average mining operation takes place at approximately 1500 to 2500m; future mines up to 6000m are being investigated. Further development in this direction will be dictated by market conditions (e.g. price of gold).

The control of water under these extreme conditions is an important part of the mining operation. This short paper describes some of the methods that have been applied successfully to control water under these rather hazardous conditions. In particular the paper presents some actual cases where **drainage to control water** has been chosen as a method and also elaborates on techniques to **control water by containing** such as high pressure grouting techniques.

In Southern Africa almost all deep mines are mining gold and uranium.

GEOLOGY AND HYDROLOGY

Gold and uranium occur in the Witwatersrand system in metamorphosed quartzitic conglomerates and in large tabular bodies termed "reef". The strike can be between horizontal and 30 degrees and the thickness of the gold bearing reef ranges from several centimeters to several metres. Gold concentration varies between 3g and 30g per tonne of gold bearing reef. The average is well below 10g/tonne, although pockets of significantly higher gold concentrations have been found and mined.

The southern part of the goldfield is overlain by relatively impervious formations such as shales, mudstones and in some areas lava. In these areas surficial ground water (perched water table) exists but is insignificant for the mining operation. However, fossil water is found below the Karoo sediments and presents a significant hazard.

In the northern part of the goldfield the overlying strata are pervious such as dolomite and are replenished continually by surface water. Surface water has been shown to rush to 500 metres below surface level in less than 24 hours. Mining under these conditions is extremely hazardous and special safety precautions and techniques are essential.

DRAINAGE AND DEWATERING OF COMPARTMENTS

Introduction

The water inflow into mining operations of the South African Goldfields is considerable. Table 1 gives an impression of the actual quantities pumped from the mines to surface.

At the same time many mines operate sections of their workings in dewatered compartments. In some areas the water table has been lowered by 1000m over a period of eight years due to mining action. (7.). For example in the dolomites of the Northern Goldfield i.e. the

Far West Rand which covers an area of approximately 1500 square kilometers to the South West of Randfontein near Johannesburg, igneous intrusions in the form of dykes subdivide these areas into reasonably watertight compartments (Fig. 1). Therefore, it is possible to dewater these compartments by pumping from underground. (15.).

Dewatering of Compartments

Dewatering of compartments in the Far West Rand commenced during 1957; ground subsidences and sinkholes occurred soon afterwards. Since the early 1960's when sinkholes and subsidences first appeared, over five hundred (500) sinkholes have occurred. Sinkholes occur without warning in a spectacular manner, sometimes with significant damage and loss of life. (December 1962, Crusher Plant West Driefontein - 29 fatalities).

Significant steps in solving the problems in this region and in finding a compromise between all concerned parties i.e. the farmers, the mines, the local industries, are given below.

1. It was felt that the dewatering on such a large scale required legislation; an Act was passed in 1956.
2. Implementation and control necessitated the formation of two organisations:
   a) A state organisation to undertake the research and the investigations and to advise the public on all matters relating to this large scale dewatering;
   b) An organisation created by the mining industry and dealing with claims by damaged parties.

   These organisations contributed significantly to the restoring of confidence in the region, in particular, after the occurrence of the first spectacular sinkhcles.
3. The Act introduced the basic principle that the mine which caused the sinkholes by dewatering is to compensate the damaged parties.
4. During the past three decades enormous strides towards the understanding of the effects of dewatering in dolomite have been made:
   a) Over 4000 boreholes have been drilled to considerable depths in the area;
   b) Intensive gravity surveys have been made;
   c) Data from shaft sinking operations and other mining activity have been collated and evaluated.
5. Recently risk assessments in these dolomites before dewatering have been made, based on aerial surveys, geophysical data, borehole data and water table monitoring.
6. Preventive measures are now introduced where dewatering is to commence.
7. Research has indicated that the following factors affect subsurface stability:
   1) The position of the original water-table.
   2) The presence of weak manganiferous residuum (Wad).
   3) The character of any overlying material.
   4) Steeply sloping bedrock contours.
   5) Bedrock pinnacles.
   6) Susceptibility to erosion of the ground profile.
   7) The ponding of surface water.

As recent as 1986 permission was granted to dewater the Gemsbokfontein compartment (Fig. 1). For the first time in South Africa significant preventive measures were taken before dewatering commenced. Indeed, the permission for dewatering was granted on the basis that the high risk areas be treated by grouting prior to commencement of dewatering.
The Gemsbokfontein compartment is not densely populated, nevertheless an important traffic route crosses the compartment. In order to protect this highway against possible sinkhole development a grouting technique was developed to stabilise the areas classified as high risk.

Grout trials were conducted; experience gained during these trials established a modus operandi: An extensive grouting programme followed where 44,000 m3 of grout were placed over 2,7 km of highway. Grout holes up to 30m were drilled. Since the start of dewatering no major subsidences or sinkholes have developed in the high risk areas which have been grouted. The grouting can be regarded as successful. (9.).

GROUTING TECHNIQUES : UNDERGROUND

Introduction

The most interesting aspects of underground high pressure grouting in the deep mines in South Africa are:

1) the use of low density (thin) grouts under high pressures and unstable under gravitational forces resulting in forced sedimentation and segregation;
2) the acceptance of appreciable deformations of the formation during grouting and operations;
3) the use of simple and robust equipment (e.g. slow rotation paddle mixers; down-the-hole packers are rarely used);

The abovementioned aspects are not acceptable in normal civil engineering grouting practice (14.) and yet grouting using these techniques has been very successful in deep mines in South Africa. This necessitates some explanation.

Underground cement grouting is essentially fissure grouting. (12.). Indeed during grouting operations it is often necessary to identify the water bearing zone or fissure and to target the grouting operation towards this zone only.

In contrast to grouting applied in civil engineering practice, underground high pressure grouting utilises water for two purposes:

1) to open the fissures i.e. deform the rock.
2) to carry the cement into the fissures to be deposited.

As the carrier "water" moves along the fissures sequential segregation takes place, i.e. the coarse cement particles settle first, then the finer particles, then the bentonite (if used) and finally the water is pressed into the formation. With this technique cover drilling can be effective over many metres.

Therefore, in essence, the technique makes use of the lack of stability of "thin" grouts. In general the method used is similar to the European technique, (19.) as the American (Australian (14.)) method using thick (dense) grouts at low pressures simply does not work in underground conditions.

In addition to these aspects, grouting in deep mines typically requires the following:

1) Large quantities are required to be injected;
2) Cement and mortar are required at many different and far away places, even in a single shaft system.
3) High pressures are necessary to overcome the hydrostatic pressure of water and to open the fissures to be injected;
4) Cement mixes of different consistencies are required at several far away places simultaneously.

Grouting Technique (Slurry Transport)

Grouting in South African deep mines serves several important functions: (6.).

1) To cover-grout any excavation made into rock for development, stopes, etc. and to combat by cement grouting water in-rushes during these routine excavations.
2) Packgrouting for supporting systems.
   This method requires the conveyance of large volumes of cement-sand mortars (Relative Density = 1,9).
3) To seal fine fissures by chemical grouting.
4) Pregrouting from surface of shafts which is described in Section 5 of this paper.

Actual operational procedures are as follows:

1) Determine conveyance parameters such as: distance and time required to transport slurry; calculate friction losses in pipe ranges, usually done empirically for the grout required; determine operation time available.
2) After drilling has been completed, install high pressure packers, connect grouting pipe and pump until expected pressure is reached.
   The grout is prepared, mixed, etc., at a central surface batching plant usually, semi-automatic and transferred to the underground relay stations. At the relay station the mix can be further adjusted (thinned) as required and reticulated to the various operational areas. Dense mortars are conveyed in the same manner to the actual supporting grout packs in the stopes.

Materials

The primary component for high pressure fissure grouting is cement and for pack grouting cement and filler, usually sand or tailings (slimes). Other pozzolanic fillers such as fly ash are also used.

The large quantities required, necessitate a compromise between a low cost material component and the required strength at the correct time.

Continual control at the surface plant of the quality of the mix is imperative.

Plant and Equipment

Plant and equipment used underground must be simple, robust and reliable. Plunger pumps capable of reaching 40MPa and higher pressures are typically used, mixing devices at the relay station are slow rotating double or single drum mixers.

The surface batching system uses typically high shear mixers to obtain a better quality grout with minimum bleeding and hence better fluidity and flow characteristics.

Drilling Techniques

Similar to the grouting equipment the drilling equipment is simple and robust. In most cases air driven, screw feed machines are used capable of drilling to 200m (AX) or more in certain cases. (10.).

Rigging of these machines is simple, but special attention is given routinely to safety features such as anchoring of the machine, etc.

PRECEMENTATION OF DEEP SHAFTS

Introduction

Pregrouting or precementation of deep shafts prior to sinking has been applied in South Africa since the fifties, with considerable success. Nevertheless, the financial and technical benefits are still very much under discussion primarily because of the difficulty of determining conclusively once a precementation has been executed whether the sinking time was in fact shortened by the pregrouting operation. Geological and geohydrological considerations are decisive parameters determining the success or failure of a precementation, indeed its desirability. (Fig. 2).

Precementation of deep shafts.

The brevity of this paper does not allow any detailed descriptions; these can be found in several publications given in the bibliography. (11.).

A short summary of the decided benefits of deep shaft precementation is given here:

1) It increases the safety of the sinking operation;
2) It minimizes the inflow of water and gas;
3) It minimizes the time lost due to additional grouting operations during sinking and hence minimizes standing time of shaft sinking crews and equipment;
4) It provides improved rock strength for excavations in the immediate vicinity of the shaft area (grouted fissures have been found up to 60m from the pregrouted shaft);
5) It provides detailed information of the geology of the proposed shaft site and information on gold grades in the shaft vicinity.

Some recent projects of shaft precementations have been listed in the following table.

Recent Projects:

	Depth Borehole (approx)	Time Months	Wedges No.	Cement Pumped Tons
EDPC 1*	2210m	-	27	278
EDPC 4*	2200m	10	47	680
EDPC 3*	2000m	13	35	840
EDPC 2*	2100m	19	68	1785
NSR	2348m	18	27	
Joel No 3 & 4 (6)**	7231m	10	39	3431
Avg. per hole	1206m		7	572
Joel No 1&2(6)**	8542m	12	57	1298
Avg. per hol 1424m		10	216	

* Reference 17
** Sum of six boreholes, one rig per hole. (11.), (Fig. 3).

Although drilling rates may reach up to 35m (N-size) in a 24 hour shift, the overall average drilling rate (including grouting, water testing, possibly some fishing operations, etc.) is closer to 5m per 24 hour shift.

UNDERGROUND CONCRETE STRUCTURES (PLUGS)

The Code of Practice of the South African Chamber of Mines (22.) for the construction of underground plugs using grout intrusion concrete is remarkable in its conceptional simplicity and striking in its in situ effectiveness. These concrete structures (plugs) are required to retain water under high pressures under normal operational and emergency conditions.

The salient characteristics of the design and construction process are as follows:

Design

1. Permission is required from the Government Mining Engineer to proceed with the project.
2. The design is simple; defining the length of the plug to be (area x pressure)/(perimeter x safe shear).
3. Safe shear in Witwatersrand quartzite is assumed to be 830kPa.
4. An important consideration is the consolidation of the surrounding rock to achieve water tightness and required strength.
5. Close supervision of construction process is essential.
6. Grouting pressure (Safety Factor included) is 2.5 times the expected hydrostatic pressure.

Construction

The construction process is simple and effective. The more interesting features are:

1. Place coarse aggregate. Recommended method is hand packing in such a manner that voids are minimized.
2. The preferred size of the coarse aggregate is 10kg (max. dimension not greater than 1/5 of the smallest dimension of the cross-section or length and not less than 75mm). Aggregates are to be cleaned and should be free from any coatings, grease, oil, etc. In general cement, coarse and fine aggregates as well as water should comply with normal concrete manufacturing specifications. Additives, though not prohibited, are not recommended as underground conditions (technical and otherwise) may be detrimental to the process.
3. Selection and preparation of a site require careful and detailed attention (no structural weaknesses, effect of mining action, preparation of rock surface to ensure adequate bonding).
4. The preparation of the grout for the intrusion process is important yet basically simple:
   a) Use not more than 30l water per 50kg of cement (W:C = 0,6).
   b) Fluidity is important due to the long distances that grout has to travel. Often remixing in transfer tanks at relay stations is required.
   c) Velocity of grout should be a minimum of 1.5m/sec. to avoid sedimentation under gravitational forces. Simple flow cone tests have been found adequate for control purposes.
   d) Unavoidable stoppages require important attention (flushing of pipe ranges etc).
   e) Strength required is 17MPa at 28 days.
   f) Final sealing pressure of the rock/plug interface is 2.5 times the anticipated hydrostatic head.

Equipment

Normal slow rotating paddle mixers and robust high pressure plunger pumps have been found to be adequate underground.

In summarizing, simple equipment that produces grout with negligible bleeding with adequate fluidity and stability (without additives) and a simple construction process is the key to the success of the concrete plugs used underground in South Africa. The design is very conservative and the method of construction is not compatible with accepted standards in the civil engineering industry but the effectiveness of these structures has been ample proof to corroborate the simple techniques used and specified in the Code of Practice.

SPECIAL TECHNIQUES

The Kombat Mine (Namibia) operates in a dolomitic area. During normal blasting operations a water in-rush occurred of such severity that the entire mine was flooded. Several miners lost their lives.

It was decided to place a concrete plug from surface at a depth of 525m. The exact position of the fissure was known nevertheless, reaching the haulage where the plug was to be placed was not an easy task.

Oil well drilling technology (down-the-hole-motor) was used to reach the required target, the mother borehole was 250mm off target at 525m.

The concrete plug was then placed through the mother hole and three deflections to obtain adequate spread. Special care had to be taken to prevent segregation during pouring. Chemical grouting was used to complete the plug and make it water tight.

CONCLUSION

In this paper the author endeavoured to show some of the techniques relating to water control under hazardous geohydrological conditions as they exist in the deep mines in South Africa.

The success of most techniques can be attributed to the simplicity in their concept and application.

Water will remain a hazard in underground operations, therefore, the control of water will always be an important aspect in mining, in future, even more so as the "easy" mining areas will eventually have yielded their treasures leaving the difficult areas (deeper, more water, less stability) to be exploited.

It is hoped that some of the techniques used now in South African deep mines can be utilised with advantage elsewhere.

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