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PRE-CEMENTATION OF DEEP SHAFT

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ABSTRACT

Pre-cementation or pre-grouting of deep shafts in South Africa is an established technique to improve safety and reduce water ingress during shaft sinking. The recent completion of several pre-cementation projects for shafts deeper than 1000m has once again highlighted the effectiveness of pre-grouting of shafts utilizing deep slimline boreholes and incorporating wireline technique for drilling and conventional deep borehole grouting techniques for pre-cementation.

Pre-cementation of deep shaft will :

- (i) Increase the safety of shaft sinking operation
- (ii) Minimize water and gas inflow during shaft sinking
- (iii) Minimize the time lost due to additional grouting operations during sinking of the shaft and hence minimize costly delays and standing time of shaft sinking crews and equipment.
- (iv) Provide detailed information of the geology of the proposed shaft site. Informations on anomalies, dykes, faults as well as reef (gold bearing conglomerates) intersections can be obtained from the evaluation of cores of the pre-cementation boreholes.
- (v) Provide improved rock strength for excavations in the immediate vicinity of the shaft area.

The paper describes pre-cementation techniques recently applied successfully from surface and some conclusions drawn for further considerations.

1 INTRODUCTION

Possibly the largest surface pre-cementation project anywhere has been completed successfully during recent months at the new H.J. Joel Gold Mine on the Orange State Goldfields (Figure 1). The project entailed the pre-grouting of the twin shaft numbers 3 and 4 up to depths of 1070m and the twin shaft numbers 1 and 2 up to depths of 1750m. In total 12 (twelve) deep hole drill rigs were deployed with capacities between 1200 and 2500m, N-size. The total quantity of cement including additives injected, amounted to 5250 tonnes. Three machines per shift were deployed and total length of 15772 m was drilled, with an additional approximate total length of re-drilling cement of 29100 m. A total of 96 wedges were placed to control and guide the boreholes around the shafts.

Drilling was done with wireline techniques throughout, injection material used was mainly ordinary portland cement (OPC). Shafts numbers 3 and 4 have been sunk successfully under virtually dry conditions. Fissures completely filled with cement were detected up to 60 m from the shaft during development. Figure 2 shows the principle of pre-cementation of a deep shaft. This paper refers to surface pre-cementation only and does not include pre-grouting during shaft sinking operations, often also referred to as cover drilling and grouting. Irrespective of whether a shaft has been pre-cemented, the Mines and Works Act No 21 of 1956 of South Africa requires adequate precautions during shaft sinking, therefore cover drilling and grouting will always be performed during shaft sinking.

2 GEOLOGICAL CONDITIONS

2.1 General

The major coalfields of the Witwatersrand basin are situated in the Transvaal and the Orange Free State. The rocks of the Witwatersrand sub-group consist of a succession of quartzites intercalated within shale bands and several gold and uranium bearing pebble conglomerates (referred to as gold reefs); these conglomerates extend over great lateral distances and to considerable depths. Gold contents of the deposits mined at present varies approximately from 2 to 20 g / ton with an average grade between 5g to 8g / ton. Average mining depth varies considerably but possibly lies between 1500 to 2200m. For example, Harmony Gold Mine milled 9,157 M tons of ore and produced 26.7 tons of gold during the financial year ending June 30th 1988; this represents a yield of 2.92 g of gold per ton milled. Subsequently, the more salient geological features of these two goldfields which produce approximately fifty percent of the world production of gold today.

2.2 The Transvaal Goldfields

A typical stratigraphic section through a part of the goldfield to the south-west of Johannesburg (West rand) is considered. The rocks under discussion dip gently to the south.

(a) Rocks of Transvaal Super-group

Pretoria Group

Succession of shales and quartzites outcropping on the large areas in the southern part of the goldfields.

Molmoni Subgroup

Succession of chert rich, chert poor and shaley dolomites with a carbonaceous shale at the base of the sub-group; these dolomites outcrop over a large areas of the goldfield with a typical thickness of 1500m.

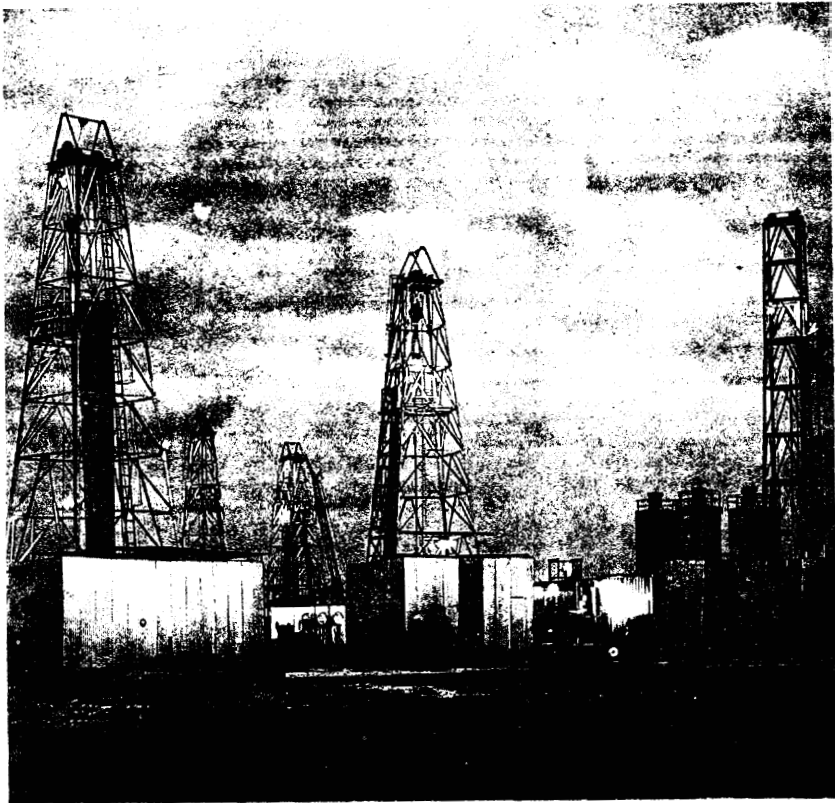


Figure 1 Pre-cementation of Shafts at H.J. Joel Gold Mine

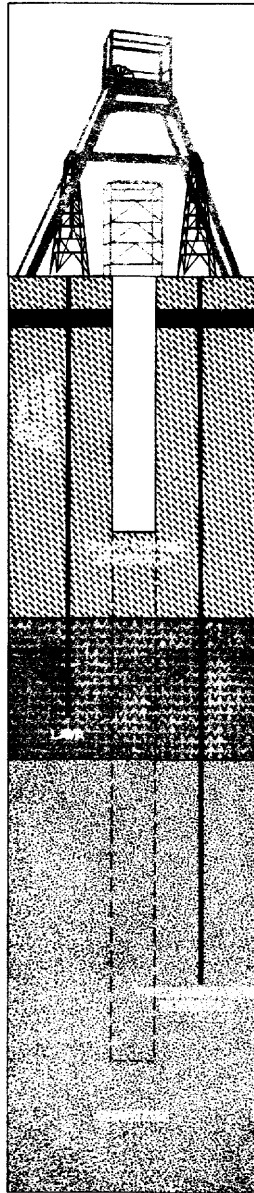


Figure 2 Principle of Pre-cementation of Shaft

- (b) Rock of the Venterdorp Sub-group
Succession of lavas; a typical thickness 900m
- (c) Rocks of Witswatersrand Super-group
Central Rand group
Succession of quartzites with gold bearing pebble conglomerates

2.3 The Orange Free State Goldfields

A typical stratigraphical section through the goldfield south of Virginia is presented as follows.

- (a) Rock of the Karoo Sequence (0-680m)
 - Beaufort group (0-130m)
Black-gray shales, micaceous sandstones and siltstones, grey mudstones, dolerite sills.
 - Ecce Group (130-580m)
Laminated black shale, siltstone and mudstone micaceous sandstone containing black carbonaceous layers and coal layers; very frequent methane gas is encountered in this sandstone.
 - Dwyka Group (580-680m)
Tillites and shales
- (b) Rocks of Venterdorp Super-group (680-960m)
 - Succession of Lavas and poorly sorted conglomerates with inter-bedded fine sediments
- (c) Rocks of Witwatersrand Sub-group (960m - 2000m +)
 - Central Rand Group
 - Homogeneous sequence of quartzites intercalated with thin shale bands and several small to medium pebble conglomerates.

2.4 Water Occurrence

In the Transvaal goldfields water occurs in the dolomites which are replenished over large areas by surface water. Except where large scale dewatering by mining operations has taken place, the water table in the dolomites is relatively high, at the same time fissured and highly jointed dolomites are a potential hazards for mining operations as they may cause enormous water inrushes with a potential danger of mine flooding.

On the Orange Free state Goldfields there are usually two water tables associated with the Karoo sediments; one occurs at shallow depth and is replenished from the surface, and the another one usually occurs in the Ecce sandstones and occurs together with the methane gas in these sandstones causing serious problems during shaft sinking.

In both areas, i.e. the Transvaal and Orange Free State goldfields water is usually present in the Witwatersrand quartzites. Several decades of mining operations however

have changed the pattern of water occurrence in these rocks significantly; in certain areas large compartments of Witwatersrand rocks have been completely dewatered.

2.5 Site Investigations

Prior to any pre-cementation and shaft sinking project although investigation of the site and an exhaustive collection of information and data relevant to the project should be undertaken. Specifically the following data would be of importance.

- (a) Sections of all boreholes in the region
- (b) Water Table levels and changes in the levels in the region.
- (c) Quality of water in the area
- (d) An analysis of areal photographs to detect possible dykes and faults.
Infrared photography in dolomitic terrain.
- (e) Magnetic survey of the region to establish possible dykes.
- (f) If possible establish joint and fissure pattern.

3 DRILLING TECHNIQUES

3.1 General

This paper is mainly concerned with pre-grouting from the surface usually executed prior or in some cases during shaft sinking. In all instances the boreholes are leading the shaft sinking operation by several hundred metres.

Grouting from the shaft bottom or cover drilling and grouting is an alternative method of pre-cementation. Safety is of primary consideration during shaft sinking and in mining in general. Therefore, a certain number of cover boreholes will always be drilled whether or not a pre-cementation has been executed from the surface. Cover drilling and grouting may be executed from the bottom of the shaft and/or from bays excavated for this purpose. In both cases the drilling and grouting operations interfere significantly with the shaft sinking operation. Normally the shaft is sunk in stages, excavation and drilling and grouting executed alternately. Percussive drilling is considerably cheaper than diamond drilling. However, the apparent low cost of this method is offset by the delays caused the standing time of the actual shaft sinking operation during drilling and grouting. Grout holes must be spaced close as grouting is limited to relatively low pressures. Therefore, pre-cementation from the surface has certain distinct advantages which are listed as a separate point in this paper.

3.2 Drilling Technique

Drilling was done by slim hole wireline drilling, generally in B and N sizes. In some cases H size was added for improved flexibility. Typically the boreholes were engineered as follows;

- (a) Drill and case overburden in a large size e.g. 115mm to approximately 30m.
- (b) Drill HQ or similar from 30-300m
- (c) Case borehole to 300m
- (d) Drill CHD-70 or similar from 300-600m
- (e) Case borehole to 300-600m
- (f) Complete borehole with BQ to 1070m

Alternatively the boreholes were completed with CHD-76 or similar up to depths of 2400m.

3.3 Drilling Equipment

For the shallow pre-cementation boreholes up to approximately 1000m, generally the TONE TEL conventional drill rig was utilized, equipped with hydraulic chuck systems, separate wire line winches and normal triplex pumps commonly used in drilling practice.

For deeper boreholes up to 1750m and in some cases up to 2400m the Joy Sullivan 45 has proved adequate. Prime movers are turbo charged diesel engine as the Transvaal and Orange Free State goldfields are situated at high altitudes, in some cases up to 1700 m.

3.4 Wedging and Deflections

Directional deflections are an essential part of surface pre-cementation projects. Conventional wedging techniques are time consuming and cumbersome, nevertheless proved very successful in hard rock typically encountered in the goldfields. Specifications usually require the boreholes to spiral around the shaft in an annulus between 8 and 25m. Shaft diameters are between 6 and 10m. Some pre-cementation boreholes have been engineered with approximately one wedge every 30m.

For the New South Roodepoort Pre-cementation project, (final depth 2340m) the initial estimate was based on two similar projects in the vicinity. With a well established and strong natural drift in the area approximately one wedge per 30m was specified. However, the judicious utilization of wireline techniques resulted in less deflection due to natural drift so that only one wedge per 100m was required to keep the borehole within the specified distance of the shaft.

Good grouting practice requires that groutable fissures be intersected normal to the plane of the fissure or at least as close to normal as possible. Therefore, wedges are introduced to improve this angle of intersection and hence increase the chances of intersecting more fissures per metre drilled. Conventional wedges facilitate a deflection of less than 2° . Boreholes are surveyed with the standard multi-shot equipment; these surveys have been found to be adequate. In general the objective is to minimize the number of wedges, or use retrievable wedges as each wedge is a potential hazard in the borehole.

4 GROUTING TECHNIQUES

4.1 General

Cement is still the primary grouting material due to its easy handling, low price and naturally its pozzolanic characteristics. It is important to realize that cement slurry is a particulate suspension and as such has intrinsic properties which need to be understood and taken cognizance of in the grouting process. Some important properties to be recognized are mentioned below;

(a) Cement slurries have a limited penetration. Ordinary Portland Cement (OPC) has a grain size distribution of approximately 5 to 9 microns. It is generally accepted that the fissures need to have a width of at least 3 to 5 times the grain size for the cement mix to penetrate effectively. Therefore, without high pressures causing deformation and hence opening of the fissure that can be grouted effectively is approximately 0.2mm. However, finer fissures may result in significant water inrushes, under high pressures and high fissure frequency.

- (b) High pressure grouting will result in differential settling of grains of different sizes. Hence large grains will settle first, then fine grains and finally additives such as bentonite will settle furthest away from the pre-cementation borehole and the shaft.
- (c) The high pressure used in grouting results in the early development of strength due to;
 - (i) The accelerated hydration of the cement because of high temperatures at depth in the borehole and because the colloidal mixing techniques generally used at present.
 - (ii) The packing of the cement grains under pressure because of the differential settling of the cement grains and as a result of the elastic response of the surrounding rock formation on the grout once the pumping pressures are decreased.
- (d) Due to the cement hydrating under near autoclaved conditions, the hydration is incomplete in the short time available before re-drilling cement. Hence the re-drilling of this cement is a hazardous exercise as the cement grains produced by the diamond drilling process are very fine, well wetted and because of the higher surrounding temperatures and frictional heat from the high rotation speed of the wire-line rods are highly active. Therefore, intense flushing and slow advance are prerequisite for successfully re-drilling cement.

A particularly dangerous situation may occur during re-drilling of cement when a total water loss occurs suddenly, allowing the fine, active cement grains to settle around the rods with disastrous consequences. As relatively low strength is adequate in the pre-grouting of shafts, fly ash, slag, bentonite or special additives can be mixed into the cement grout in order to delay the settling, reduce the differential settling but, nevertheless, develop a reasonable strength after few weeks. Subsequent discussions are limited to cement grouting techniques; rock treatment by chemical grouting is beyond the scope of this paper. Cement grouting theory and application fall into two diametrically opposite schools of thought. On the one side high pressure grouting is widely used in Europe and in South Africa, particularly in the mining industry and on the other side low pressure grouting is mainly applied in the USA and Australia.

High pressure grouting is associated with relatively thin cement mixes, in some cases as thin as 8:1, W:C ratio by mass. However, most importantly high pressure grouting is associated with the deformation of the formation due to the high pressure used. In contrast low pressure grouting is associated with negligible deformation of the soil and rock structure and in general only thick non-bleeding cement mixes are utilized.

4.2 Grouting Techniques

4.2.1 Grouting Equipment

A standard grouting unit utilized for a typical deep shaft pre-cementation comprises the following:

1x 55 tonnes silo for cement complete screw feed conveyor

1x 55 Tonnes silo for P.F.A. complete with screw feed conveyor.

1x electric mixing plant consisting of one primary mixing vessel of 630 Litre and two secondary mixing vessels of 630 litres each, a transfer pump and control panel. The mixing plant has a capacity of 17 tonnes of solids per hour which equals to 20,000 Litres of 1:1 grout mix.

2x air driven grout pumps with a capacity to deliver 5000 Litres of grout mix/hour at pressures in excess of 20 MPa.

1x Compressor (750 cfm)

A number of back-up silos per unit up to a total storage capacity of 330 tonnes may be required to grout continuously also during the weekend operations.

4.2.2 Grout Mix

The constituent materials of the grout mix that may be used are cement, P.F. A (pulverized fuel ash) and bentonite. These three components of the solid portion of the grout mix are normally added in the following proportions:

PFA	75%
Cement	20%
Bentonite	5%

The addition of PFA to the grout mix is done for economic considerations since it is substantially cheaper than cement with an acceptable loss in the final strength of the grout. Coloured dyes have been added to this solid portion in small quantities to trace cement paths. The Ratio solid to liquid of a grout mix is determined by the results of the water pressure test before commencement of the grouting. Starting mixes can be as thin as 6:1,W:C by mass and may be thickened to 1:1 W:C by mass or even denser.

4.2.3 Grouting Procedure

4.2.3.1 Grouting is carried out when the following conditions occur.

- o Excessive water acceptance during water pressures tests. Water pressure tests are conducted at regular intervals and when a noticeable loss of drilling fluid occurs,
- o Total water loss condition
- o After an ungrouted interval has been drilled, typically not more than 100m.

4.3.2.2 Grout Injection

The borehole is flushed with water prior to grouting to remove remnants of the drilling fluids, then a water pressure test is carried out. The solid to liquid ratio of the starting grout mix is determined. The injection starts by pumping a certain number of mixes of water and bentonite followed by injection of the selected starting mix. The consistency of the mix is gradually changed - according to the pressures obtained- in order to pump grout mix as thick as the fissure can absorb without choking.

The sealing pressure of a grout zone should not exceed the value 2.5 times the hydraulic head in the area. At the end of the grout injection, when sealing pressure is reached, the grout manifold is closed until the pressure in the system has dropped to zero. Thereafter the unset grout mix is flushed out of the borehole until hardness increases and re-drilling of the solid grout starts. On completion of the re-drilling a water pressure test is carried out to assess the effectiveness of the grouting. This test will be undertaken up to a pressure of not more than 2.5 times the hydraulic head of the area.

Generalizations of grout absorption are difficult to make and often unreliable. Nevertheless it is interesting to note that the overall absorption for the Karoo sediments of the O.F.S. goldfields was approximately 50 kg cement per metre whereas the equivalent figure for the central group rocks in the same area was 2000kg cement per meter.

5 RECENT PROJECTS

Some recent projects of shaft pre-cementations have been listed in the following table. Although drilling rates may be up to 35m (N-size) in 24 hour day, the overall drilling rate including grouting, water testing, possibly some fishing operations,etc.) is closer to 5m per 24 hour period.[Reference 7]

	Depth Borehole Appx.	Time Months	Wedges	Cement Pumped Tonnes
	m			
EDPC 1 [Ref.7]	2210	-	27	309
EDPC 4 [Ref 7]	2200	10	47	756
EDPC 3	2000	13	35	933
EDPC 2	2100	19	68	1983
NSR	2348	18	27	-
Joel No 3 &4 [Ref 6] *	7231	10	39	3812
Average /hole	1206	-	7	692
Joel No 1 &2 [Ref 6] *	8542	12	57	1442
Average /hole	1425		10	240

* Sum of six boreholes

6 CONCLUSIONS

Based on the experience of several large pre-cementation projects the following conclusions can be made:

1. Pre-cementation of deep shafts is technically feasible and can be economical.
2. Pre-cementation increases the safety of the shaft sinking operation.
3. Pre-cementation minimizes the water and gas inflow during shaft sinking.
4. Pre-cementation reduces the time lost due to grouting during sinking operations. Costly delays and standing time of sinking crew and equipment is significantly reduced.
5. Pre-cementation improves rock strength for excavations (station etc.) in the immediate vicinity of the shaft area.

6. Pre-cementation provides advanced detailed geological information that may be important for the mine as well as the contractor.

Several additional observations based on pre-cementation in general may be of interest:

- (i) The behaviour of grout including the distance of travel, penetration, etc, the actual grouting procedure, optimal grouting pressures still require research and more experience.
- (ii) Equipment such as pumps and drill rods have a shorter life due to the high abrasion characteristic of cement.
- (iii) The presence of wedges remains a hazardous factor, nevertheless good results have been obtained.
- (iv) A meticulous and comprehensive site investigation is a prerequisite for the success of a pre-cementation operation. In particular the determination of the natural drift of boreholes in the area may reduce the number of wedges required and hence reduce the overall risk of the drilling operation.
- (v) Piloting by large diameter percussive drilling is recommended due to the large deflection of boreholes, spiraling of boreholes, etc, with this drilling technique.
- (vi) One borehole per shaft may be adequate under certain circumstances as additional deflections can be achieved by guiding the boreholes around the shaft by the installation of wedges.
- (vii) Although cement is normally re-drilled with non-coring bits, in certain cases the prints obtained from the fissures in cement cores provide interesting information on the way the grout entered the fissures and on the deformation of the fissure under pressure during the grouting procedure.

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