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ASPECTS OF ADVANCED GROUTING DURING SHAFT SINKING IN SOUTH AFRICA

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ABSTRACT

Fixed costs for shaft sinking operations are extremely high, therefore precautions must be taken to avoid unproductive standing time of the shaft sinking crew. Water in-rushes or unconsolidated grounds sometimes cause stoppages to sinking operations because the sidewalls must be sealed or stabilised. Pregrouting can to a large extent avoid such delays. The paper describes ways and means how to execute pregrouting under varying conditions and draws attention to problems which may be encountered. The author concludes that the cost for preventive grouting operations are small compared with the overall expenses of shaft sinking operations and the cost of unproductive standing time.

INTRODUCTION

Overhead costs for sinking large diameter shafts are known to be upwards of U.S. $250,000 per month, irrespective of meters sunk. Therefore every effort which will allow to speed up shaft-sinking and save unproductive time is economically justified. The overhead costs of shaft sinking are for all practical purposes rise disportionately with standing time. One of the main causes which delays shaft sinking operations is the ingress of water during excavation. The nature and size of water bearing fissures or cavities in the vicinity of the future shaft depend of course largely on the type of rock. Dolomites, which cover wide areas of the Transvaal are known to be highly water bearing formations. However, other rock types, such as shales and lavas, can yield considerable quantities of water, if intersected in the course of sinking operations.

In South Africa, Colliery shafts are usually very shallow. Shafts for gold or base mineral mines are often of considerable depth, sometimes well beyond 1000 m.

Quantities of water which were struck during shaft sinking operations in Southern Africa have varied tremendously but from the author's personal knowledge have been as much as 200,000 litres/hour, resulting in the loss of the shafts in certain cases.

The best method of dealing with water hazard is to drill holes ahead of the excavation and if water bearing fissures are intersected, inject any suitable material (cement, slime, sand, bentonite, chemicals) in order to fill the fissures and thus seal them properly. Grouting may however also become necessary in order to consolidate some unstable overburden and/or weathered or broken rock. In any case the basic intention of all pregrouting operations is to create a homogeneous block of soil or rock, through which the shaft can safely be excavated.

Various methods and techniques of foregrouting shaft exist and some of the important aspects of the grouting are discussed in this paper.

METHODS OF PREGROUTING

A pregrouting programme generally consists of drilling holes of a suitable size within or close proximity to the perimeter of the shaft and whenever water bearing fissures are encountered of injecting cement to which suitable fillers can be added. Two basically different methods are presently being applied :

(1) Grouting from the Shaft Bottom

This method foresees grouting through holes which are drilled by means of pneumatic machines from the respective shaft bottom either within the section of the shaft or from especially excavated bays. Drilling from the shaft bottom interferes considerably with the organisation of the actual shaft sinking crew; drilling from bays demands more excavation and subsequently more concrete for lining.

Such holes, the number of which may vary according to the local conditions, are generally drilled to a depth of 30 to 50 m and then injected. When the grouting is completed, the shafts are excavated to a depth of about 6 m above the bottom of the treated zone in order to leave a cover against water inrushes from below. From this newly reached shaft bottom, another series of holes are drilled and grouted. The shaft is thus sunk in stages, excavation and grouting being executed alternatively. The advantages of this method lie in its apparent low cost because percussion drilled holes are considerably cheaper than diamond drilled ones. The drawback however, is the standing time of the actual shaft sinking which usually overcompensates the savings in drilling.

Further, on technical grounds, some reservations are to be made. Sinking and grouting cannot be done simultaneously. All excavation work has to be stopped while drilling and grouting is in progress. Drilling from bays is hampered by lack of space and costs therefore much more time than drilling from the shaft bottom. Consequently, there is never sufficient time to carry out the grouting as carefully as is necessary, because the shaft sinkers are pressing to continue the excavation.

Injection work from the floor of the shaft forbids the application of high injection pressure otherwise the grout may break through into the shaft from the bottom or through the sidewalls or may even displace and damage the lining higher up. Therefore, the grout holes must be spaced very closely to each other in order to compensate for the rather small range of spread due to low pressure allowed.

(2) Precementation from surface

The aforementioned difficulties can be avoided when precementation is done from surface before excavation commences. The cover holes are laid out near or along the perimeter of the shaft and can be drilled down to any required depth, well before the actual shaft sinking is started. This demands, undoubtedly, time before excavation can take place. However, it eliminates almost all interruptions and delays arising from ground water and broken rock during the actual shaft sinking which is burdened with very high fixed overhead costs.

On the other hand, the relevant expenses for an uninterrupted precementation job are small only compared with the total cost of the shaft although drilling is done by the rotation method.

(a) Drilling

(i) Number of Holes -

The number of holes to be drilled for precementation from surface is dependent of :

- The expected formations which influence the extent of the spread of grout.
- The capacity of the injection pumps.
- The diameter of the shaft.

It is strongly advisable to have in the case of big diameter shafts, besides the circumferential ones, also a centre hole.

(ii) Drilling Procedure

The drilling is usually done in stages of approximately 30 m and a water pressure test is executed afterwards. On the outcome of such test, it is decided whether grouting at that stage is necessary or not. It must also be mentioned here that no holes can, over long stretches be maintained straight. The tendency to wander is greater the smaller the diameter. Regular surveys of the holes are indispensible and deflections may become necessary. Practise has shown that a wedge in hard rock can correct the direction of a hole by only 1½°and maximum 2° in the cases of BX and NM holes (60 mm/76 mm). In order to treat only the rock in the immediate vicinity of the future execavation, the straightness of the holes is of utmost importance and all possible care must be taken to achieve reasonably vertical and straight holes.

(b) Deviations

The smaller the drilling diameter in relation to the length of a hole, the greater is the tendency to deviate, which is caused by one or several of the following features :

- Worn rods or corebarrels, rods much smaller than the drillhole respectively loose threads and fittings resulting in lack of concentricity.

- Drill rotation tending to produce a spiralled hole.
- Stratification or schistosity or faulting of formation. In general with the inclinations from 0° - 45° from the horizontal, the drillhole tends to become more nearly perpendicular to these planes. With steeper angles or at some particular critical angle, it tends to follow the cleavage of bedding planes.
- Alternating formations of hard and soft layers tending to force the hole towards the softer materials.
- Also factors such as type or condition of bit, nature of feed, bit pressure and flush water pressure all have some influence.

(c) Grouting

(i) Method

When grounting becomes necessary, it can be done by capping the standpipe of the hole and arranging for some access through the lid. This is the conventional and not recommendable method. The hole should better be plugged at the bottom of the foregoing injection stage with a suitable packer because :

- This allows to step up the injection pressure with increasing depth
- When a hole is always plugged at or near the surface, such higher pressure which is necessary for deeper zones may reopen fissures in a stage which was previously sealed at lower pressure.
- The amount of redrilling is much smaller, therefore, the saving in time and cost is considerable.

Care must be taken to prepare the right mixture consistent with the type of rock and the nature of fissures.

Whether a stage must be injected or not and the initial viscosity of the grout is decided upon the result of the foregoing water test.

Pumping is carried on uninterruptedly until the set max. pressure is reached.

Note : Experience has shown that presently in small diameter holes (AX, BX, NX) (48 mm; 60 mm; 76 mm) packers for withstanding pressures of more than 200 bar can often not be placed effectively in depths greater than 200 m. The author's company has obturators available which can safely be positioned considerably deeper down.

(d) Pressure

Once a depth of more than 150 m is reached, the injection pressure is increased to more than 100 bar. This allows to use comparatively thick mixtures. The advantages arising therefrom are :

- The operation becomes more economical as more solid (sealing) material is pumped during a given time.

- It is technically sounder to control the spread of grout by varying the composition of the mixture than by limiting the injection pressure. Chemical additives can do a lot of good if skillfully applied.
- High pressure can force soft, dirty material out of small fissures which, at low pressure would never be properly cleaned and sealed.
- When grouting is done in greater depths at comparatively high pressure an occasional widening of fissures cannot be excluded. It is, however, accepted as unavoidable. As there are usually not yet permanent underground installations in the vicinity no undue risks must be faced.

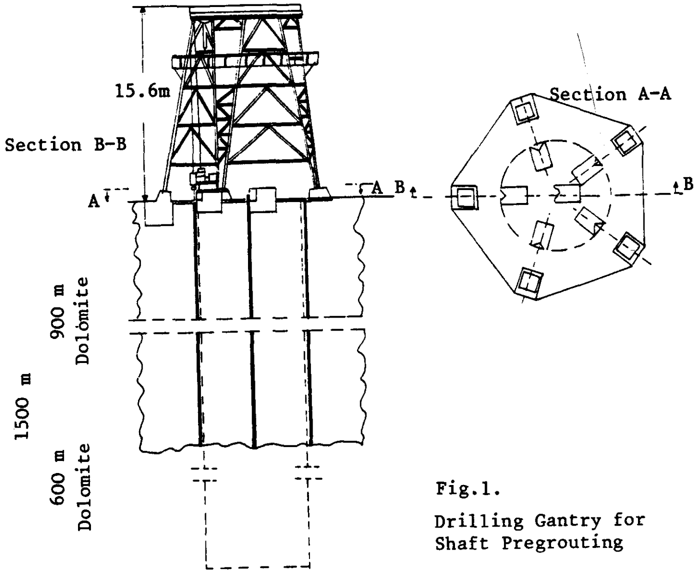

Fig.1.
Drilling Gantry for Shaft Pregrouting

Grouting Plant

Fig.1 shows drilling tower constructed to serve 6 pregrouting holes with only three machines. Once a stage was drilled the rig and the rods were lifted and placed on the mouth of another hole which had been grouted in the meantime. The redrilling of set grout and further drilling of new ground would commence.

By this arrangement standing time of the heavy drilling machines which were to go down to approximately 1000 m was virtually none at all. Together with the overall saving of time this has compensated for the cost of the special derrick. A centralised mechanically operated dosing, mixing and pumping plant is normally installed for grouting, which can handle with an accuracy of not more than ± 2% tolerance at least 3 components. Example : water, cement and filler or water, cement and bentonite.

It is not advisable to inject at the same time more than one hole. Exceptions can however be allowed, when the stages awiting treatment are located at a considerable distance in depth and it is known that no subvertical fissures exist.

- A reputable contractor will execute water pressure tests, which precede any grouting by employing a continuously recording instrument which automatically produces a written graph.
- All injection pumps are fitted with a self-recording pressure gauge, the readings of which must be carefully studied and interpreted in order to obtain data, which allow to assess the existing ground conditions in the zone under treatment.

Mixtures

The grouts to be injected must be technically adequate for the required purpose and cheap.

Much consideration has been given and a lot of studies have been invested into this matter. The schedules, Table 1 to 5 give particulars in respect of binders, fillers, additives, characteristics of various compositions with regard to sedimentation and segregation. The details included also deal with volumetric index, viscosity, setting time, and mechanical strength.

Table 1

Compressive Strength of Binders (Comparison)

Binders	7 Days	28 Days
Portland Cement	100.00%	100.00%
Portland Blast Furnace Cement	63.10-71.88	84.20-85.90%
Portland Cement + Slag :		
ratio 75/25	83.00%	101.00%
ratio 50/50	65.80-74.2%	81.30-88.50%

Inert Fillers

Grain Size : Below 0,60 mm, the grains tend to floculate, making it difficult to establish a grain-size curve for the finer portion. Slime is somewhat coarser than the Portland Cement with which it is mixed.

Sieve Curve of Mine Tailings (slime) as compared to ordinary Portland cement :

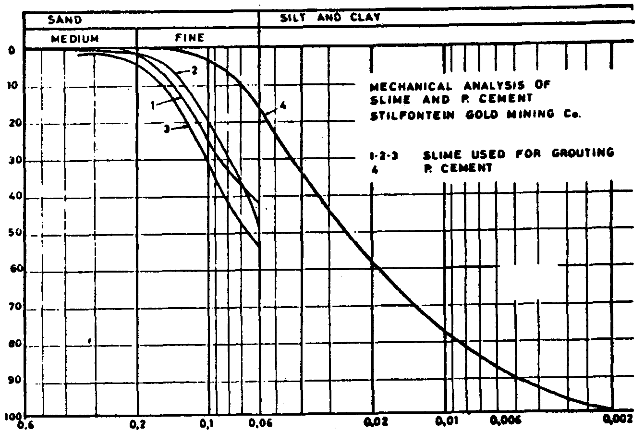

Table 2

Chemical Composition of three selected samples

SiO_2	89.3%	96.5%	98.74%
Al_2O_3	6.4%	2.2%	1.13%
Fe_2O_3	1.2%		
SO_3	1.8%	-	-
Trace Elements	1.3%	1.3%	0.13%
	100.0%	100.0%	100.0%

Table 3

Mechanical Strength of Hardened Grouts

Ratio of Solids PC:	PBFC:	SLAG:	SLIME:	Water %	Specif. Mass	Compr. Strth. after 7 Days %	28 Days %
100	-	-	0	35.7	2.08	100.00	100.00
75	-	-	25	33.7	2.02	65.4	78.1
50	-	-	50	31.8	1.97	34.3	37.1
25	-	-	75	29.8	1.93	9.8	14.8
-	100	-	0	33.6	2.06	71.8	84.2
-	75	-	25	32.1	1.96	40.8	62.9
-	50	-	50	30.7	1.94	19.7	35.3
-	25	-	75	29.2	1.91	7.9	14.4
50	-	50	0	33.4	2.07	74.2	81.3
32.5	-	32.5	25	32.0	2.00	62.1	68.3
25.0	-	25.0	50	30.6	1.97	38.8	48.5
12.5	-	12.5	75	29.2	1.88	9.9	19.2

PC + Slime

The strength at 7 days bears witness to the retarding effect of the impurities of the slime.

PBFC + Slime

PBFC appears to be less sensitive than PC to the effect of the impurities of the slime, when in a proportion above 50%.

Table 4

Setting Time of Grouts

Portl. Cem.	Slime	Beginning	End
100	0	3 hrs 50 min	6 hrs 10 min
90	10	4 hrs	6 hrs 20 min
80	20	4 hrs 10 min	6 hrs 40 min
70	30	4 hrs 20 min	7 hrs
60	40	4 hrs 35 min	7 hrs 30 min
50	50	5 hrs	8 hrs

These times are within the limits prescribed by the British Standards : not less than 30 minutes, but no more than 10 hours.

The beginning of the setting time shows the time available for mixing, transporting and injecting the grout into the rock fissures. The end shows the delay before the mine work (blasting) may safely be started.

Note : P.C. = Portl. Cement; P.B.F.C. = Portl. Blast Furnace Cement

Table 5

Certain Characteristics of Solids

Binders	Sp. Mass	Blaine cm^2/gr	Liquid Limit	Plastic Limit	Chemical Composition% CaO	SiO	MGO
Portland Cem	3 113	3020	-	-	64.7	21.8	1.7
PBFC	3 010	3250	-	-	50.4	26.8	8.1
Slag	2 902	3520	-	-	30.8	32.4	19.9
Fillers :							
Ground Quartz	2 610– 2 770	4540	-	-			
Slime	2 647	1920	-	-			
Additives :							
Bentonite (Wyoming)	2 420	-	554	38.4			
S.A. Bentonite	-	-	526	42.8			
Bentonite Clay							
(Natural)	-	-	101.5	-			
(Activated)	-	-	134.0	-			

Table 6

Viscosity of Bentonite

	Marsh viscosity (seconds) for Bentonite plus water, (ratio by weight) 1%	5%
Wyoming Bentonite (natural)	13 6	17 5
South African Bentonite (activated)	13 8	19 2
Bentonite Clay (natural)	13 1	13 2
Bentonite Clay (activated)	13 3	13 8

The Marsh viscosity of a bentonite suspension is accepted as a measure of efficiency in respect of sedimentation and volumetric index, but not as a measure of pumpability.

Table 7

Volumetric Index of Grouts

Portland Cement	Slime	Bentonite	W/S Ratio
100	0	0	0·27
100	0	2	0·365
75	25	2	0·36
50	50	2	0·35

Bentonite increases the amount of water permanently retained, thus improves the volumetric index.

SEALING OF VERTICAL FISSURES

If very steep or vertical fissures are existent, they can usually not be intersected by precementation holes which stretch parallel to the shaft axis, as is the case when drilling is done from surface. When such conditions are encountered, grout holes must be drilled inclined. This can practically be done from the respective bottom of the shaft only.

SUMMARY

If, during a shaft operation, water is intersected, drilling and grouting has to be done in any case. During that time, the sinking crew will be idle while their heavy overhead cost will continue to run.

There exists practically no safe method to limit the spread of injected grout only within a certain zone. There is always the danger that grout is pushed too far. An experienced operator can, however, by interpreting the pressure reading and by varying the composition of the mix, control somewhat the propagation of the grout. But whatever the unavoidable waste of material may be, it must be seen in the light of what it will cost if the shaft sinkers are kept unproductive.

When the excavation of the shaft is stopped for only one day, . U.S. $8,000,00 fixed cost will be lost. Such an amount is the approximate equivalent of 50 tons of cement injected, which fact shows again under a different aspect how negligible the expenses for pregrouting are when compared with the cost of shaft sinking in general.

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