Cover drilling and cementation of water fissure during shaft sinking and the use of micro fine cement as a grouting medium

Petrus Johannes Lodewikus Nel[1], Tom Arild Melbye[2], Hans Olav Hognestad[3]

[1]*Shaft Sinkers International (Pty) Limited, Centex Office Park, Katherine Street, Sandton, Republic of South Africa. e-mail:nel@shaftsinkersint.co.za*
[2]*MBT International Underground Construction Group, Vulkanstrasse 110, 8048 Zürich, Switzerland. e-mail:Tom.Melbye@mbt.com*
[3]*MBT International Underground Construction Group, Vulkanstrasse 110, 8048 Zürich, Switzerland. e-mail:hans.olav.hognestad@mbt.com*

Abstract: This paper deals with the cover drilling, grouting techniques applied and the specific use of micro fine cement as a grouting material for the sealing of water fissures in sinking shafts down to 3500 m below surface. In this context, it is also central how to use and take advantage of stable and low viscosity micro cement grout.

The main purpose of grouting is to effectively seal in the shortest possible time, all water and gas bearing fissures before exposing them with the excavation. Modern sinking methods employed do not make provision for the handling of water in excess of 4 ∝/ sec and any such excess thus seriously impeded on the progress and obviously capital costs.

No single factor influences total cost of shaft sinking as much as time. The materials cost using OPC in a grouting operation may amount to around 5% of the total, while time related cost would be more than 60%. The higher material cost of Rheocem 650 compared to OPC is substantial when comparing kg-prices, but when time is saved the overall cost is often substantially lower.

This is possible because of a set of grout properties of Rheocem 650, especially developed for the tunnelling and shaft-sinking environment.

1 INTRODUCTION

Cover drilling and pre-injection ahead of the advancing shaft / tunnel face is a standard practice employed in Republic of South Africa and is becoming a very important aspect in shaft sinking and tunneling. The method however is sometimes conceived as very expensive and time consuming by clients and consultants, and results whether satisfactory doubted.

Increasing economical demands on contractors can be met by :

- Limiting water drainage into excavations by cover drilling and cementation.
- Application of modern drilling equipment in combination with state-of-the-art injection equipment and injection materials have improved the efficiency of the methods substantially, widening the field of application.

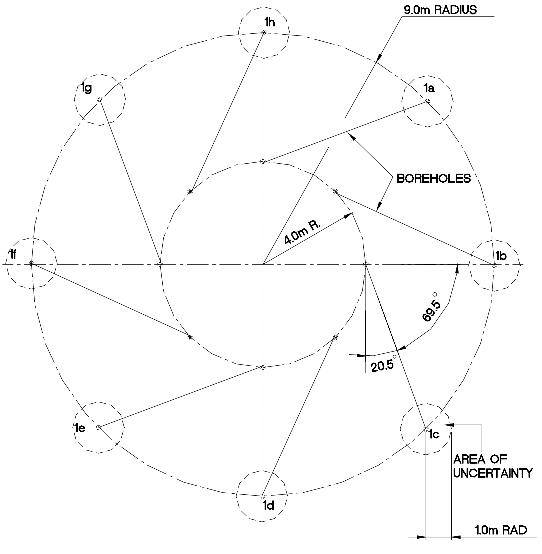
It is a known fact in the construction world that there is international pressure for all companies to find less expensive methods within shaft and tunnel construction.

Controlling ground water during shaft sinking and tunneling is a complicated factor and especially if shotcrete is required either as a temporary support close to the advancing face with concrete / shotcrete following as permanent support. With wet face conditions it would simply not be possible to produce a high quality concrete or shotcrete lining that would be acceptable as a permanent lining.

This is where the importance of cover drilling and cementation comes in as part of the standard procedure.

2 DESIGN OF COVER ROUND

The standard cover round design should be such that all the holes drilled will intersect a point approximately 6 metres outside the shaft/ tunnel excavated diameter at the projected drilling depth and radially in line with the collar of the adjacent clockwise hole (Figure 1). The design must ensure that one or more of



plan on shaft bottom
showing cover round

Figure 1 Typical shaft cover drilling configuration for an 8.0 m diameter shaft.
Radius of borehole collars 3.0 m; Length of borehole drilled 36 m; Radius of uncertainty of end hole 1.0 m; Angle of spin of boreholes 69.5 from the extention of radial line drawn through borehole collar or 20.5 outwards from the tangent to the shaft at the borehole collar; Angle of rake of boreholes 10.5 off vertical

the holes will intersect the plane of any randomly orientated water bearing fault or fissure in the ground ahead of the shaft being sunk. The 6 metre projected point is of extreme importance as any distance closer than 4,5 metres to the excavation line might suffer blast damage and result in leakage from fissures sealed previously. The design length of the round is also important in that the longer the round the bigger the possibility of deflections and inaccuracies resulting therefrom.

It is recommended that on completion of the Cover Round all holes are to be grouted and sealed irrespective of whether or not water was intersected.

3 COVER DRILL PROCEDURE

The paper will deal mainly with experiences obtained during applications at a 800 metre deep shaft sunk at Sedrun, part of the new Gotthard base Tunnel in Switzerland and 2 x 26° declines being sunk at ± 1000 metres below surface in Botswana.

Cover drilling commences with the systematic drilling of a designed record referred to in Figure 1. The cover rounds are drilled at normally 36 metres intervals as depicted in Figure 2.

Holes are drilled through pre-set grouted casings fitted with H.P. drill cocks and stuffing boxes which will ensure shut off facilities in case of intersecting high pressure water or gas. (Figure 3).

If water is intersected during the drilling of these holes, the hole should be extended approximately 1 metre beyond the intersection and prepared for injection.

4 SHAFT INJECTION ECONOMY

The characteristic situation in all modern tunneling/ shaft sinking, is that the speed of the shaft advance is decisive in the overall economy. This fact is closely linked to the very high investment in equipment, causing high equipment capital cost. The capital invested in modern hydraulic drill jumbos and other equipment necessary for drill and
blast, is substantial. In addition to this, the limited working space at the shaft face is normally such that only one operation can take place at a time.

The shaft advance rate is decided by the number of hours available for actual excavation works. When one hour of face time typically has a value of about USD 1500.- it becomes evident, that a close check on the cost-benefit of all face activities is a must. From this, it can be seen, that injection in a sinking/ tunneling environment is basically different from injection for dam foundations

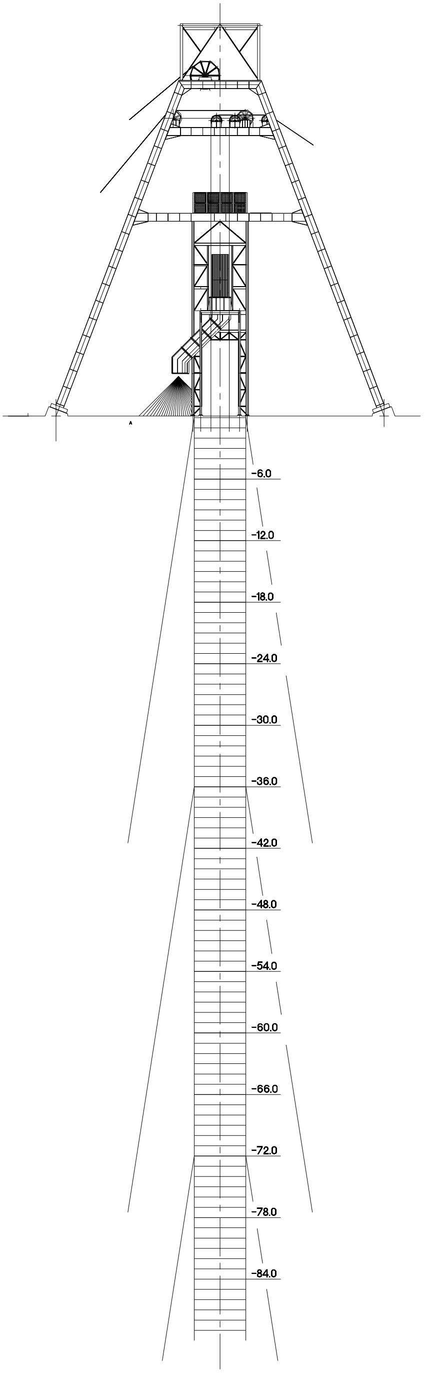


Figure 2

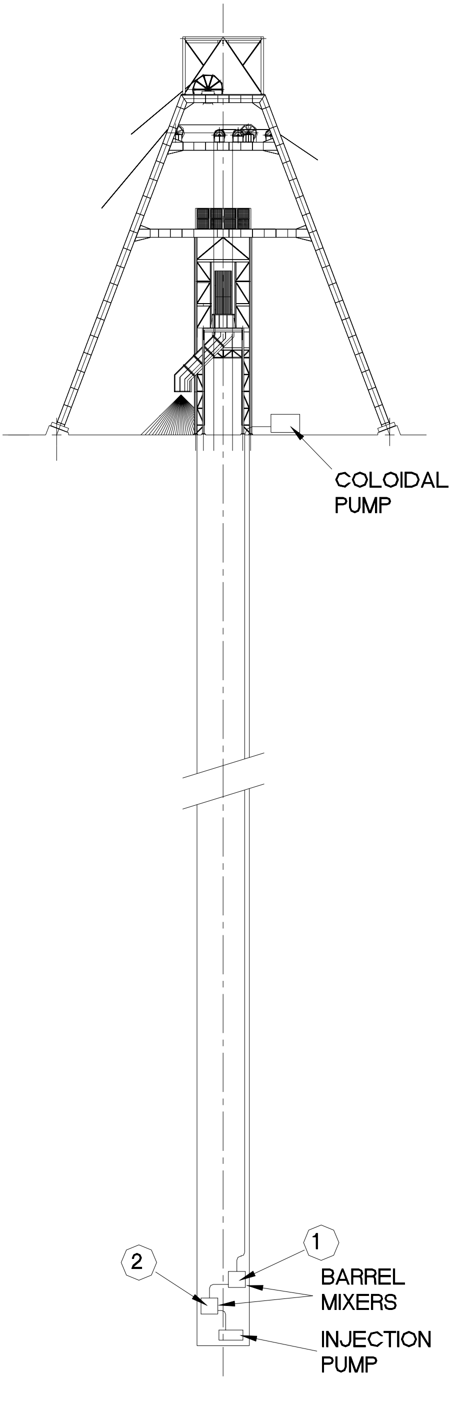


Figure 3

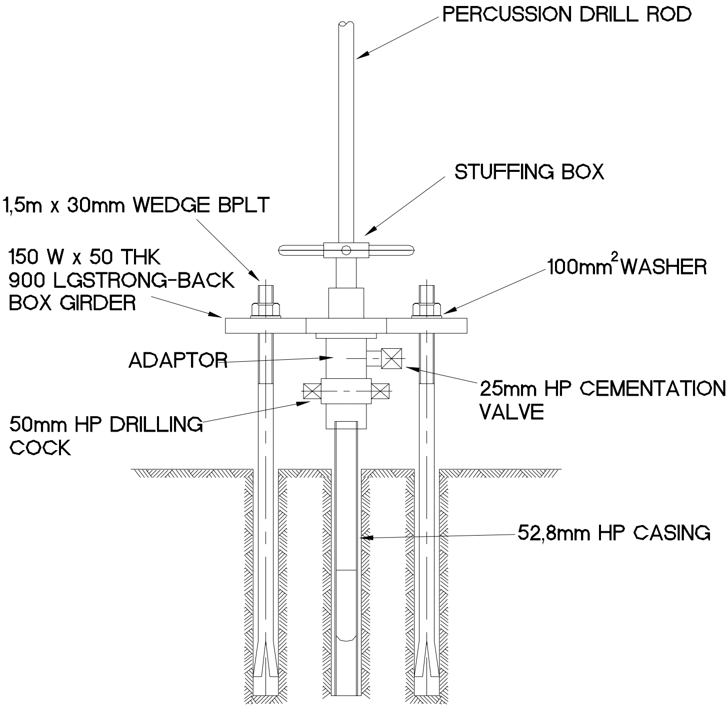


Figure 4 Percussion cover drill casing

and surface ground treatment. The drive for more efficient methods, materials and equipment has therefore been very strong.

Cementitious grouts

Cement has been the grouting material of first choice for decades. In caparison, the chemical grouts are relatively expensive and in many cases there are problems related to the working environment and the working safety. Depending on the purposes of the grouting and ground condition, chemical grouts may also produce unsatisfactory durability. Most of the chemical grouts require special equipment as well, e.g., two-component pumps.

The latest decade has given a number of new cement based products for injection. Typically, these cements are much finer and may offer adapted setting and hardening characteristics. In many cases, these cements are combined with admixtures, to provide entirely new cement grout properties and substantially improved penetration. Even though these new cement products are more expensive than standard Portland cements, these are still very competitive, compared to chemical grouts and standard cements.

The MBT Rheocem range of micro cements consists of three different grades:

- Rheocem 650 Blaine value of > 625 m^2/kg, dmax 95% 18 μm
- Rheocem 800 Blaine value of > 800 m^2/kg, dmax 95% 12 μm
- Rheocem 900 Blaine value of > 900 m^2/kg, dmax 95% 8 μm

These micro cements are always all used with the admixture Rheobuild 2000PF at a dosage rate of 1.5 - 2% by weight. The admixture is an integral part of the system and has the following functions:

- Works as a dispersing agent during mixing, to ensure proper wetting of cement particles
- Prevents flocculation between time of mixing and time of injection
- Gives water retention stability under injection pressure (very important for penetration)
- Strong reduction of water quantity required for a given suspension viscosity.

The mix design normally used for a non-bleeding, low viscosity grout is, w/c-ration 1.0 with 1.5% by weight of admixture Rheobuild 2000 PF typical properties of this grout are:

- Flow cone time of 32 to 34 s (pure water gives 27 s)
- Maximum bleeding of 1%
- Initial setting time 60 to 120 minutes, final setting time 120 to 150 minutes
- Mud balance 1.48 to 1.50 kg/l
- Compressive strength after 28d>10 Mpa

A special feature of the Rheocem range of grouts is the quick strength development, still with sufficient open time in the equipment. This is important for overall economy at the shaft bottom, since time related cost can be saved. It is furthermore important that this is achieved without the use of accelerator, because such admixture would cause immediate flocculation, which is defeating the purpose of using micro cement in the first place.

The Rheocem micro cements are compatible with the Delvocrete Stabilizer Hydration Control System. In cases where longer open time is required even hours can be achieved without a flowability loss.

With other micro cements and normal fine cements it is not unusual to wait as much as 16 to 24 hours, concurrently with the advance rate, and hence, total costs.

It is also important to have a mix which is stable under pressure and to avoid particle flocking in the fissures. Rheocem with Rheobuild 2000PF at a W/C ration of 1 gives less than 1% bleeding. This is to avoid bleeding channels and incomplete injection.

Because of the quick setting there is only a minimal costly waiting time after a completed injection before probe-drilling or drilling for a new blasting round can be started. The injection time is also dramatically reduced as the pressure and tightness are reached with far less materials per hole / injection round, because of reduced penetration of the Rheocem grout outside of the required injection area around the shaft (due to the quick setting) and it is not like with normal OPC that can be pushed hundreds of metres away for no use. Therefore with Rheocem micro cements you can safe as much as 50% of the time compared to traditional OPC.

Only one mix design is recommended : W/C ratio = 1 with 1.5% Rheobuild 2000PF added. This has considerable advantages for the crew because possible misunderstandings and wrong mix designs - as with normal cement - are being avoided.

With other microcements and normal fine cements, it is not unusual to wait more than 16 hours - 24 hours. With the implication this has on advance rate and total costs.

It is also important to have a stable mix. Rheocem with Rheobuild 2000 PF at a W/C ratio = 1 gives not more than 1% bleeding.

Mixing:

1 Add water to the coloidal mixer.
2 Add cement.
3 Mix for about 2 minutes
4 Add Rheobuild 2000 PF
5 Mix for 1 minute more.

Pump the mix from the coloidal mixer to the receiving hopper, at the top of the shaft, and to drop it down, into the paddle mixer at the bottom of the shaft. It is important that the mix is prepared in the right time. This means it should not be made before the injection crew in the shaft signal for a new mix (only work with fresh mix).

It is very dangerous to have the mix in the mixer too long. During mixing the friction creates heat. If the mix becomes too hot, it may set prematurely in the equipment.

For the same reason, the agitator should be empty or almost empty before a new mix is added.

Testing:

It is of the utmost importance to test whether the sealing was successful, prior to commence with blasting. The standard practice in Republic of South Africa is to re-drill and if necessary extend the cover hole to its full designed depth (if water was intersected prior to completing) with normal OPC a minimum of 16 hours is required before re-drilling can be attempted. Using micro cement the re-drilling can be done after 3 to 4 hours, resulting in a time saving of 12 hours. Considering the face time of $1500- per hour mentioned earlier the saving in time and costs are significant.

The other important aspect to keep in mind is the fact that in a 8 metre shaft at least 8 holes are required and if several of these intersect fissures which are not connected the setting time using OPC could be enormous.

Stop criteria for Rheocem grouting

You should inject and not stop / interrupt the injection before any 9 of the two stop criteria listed below has been reached.

A. Constant injection pressure of 60 to 80 bar - above possible ground water pressure / water pressure recorded at the start of the injection.

or

B. You have injected 2000 kg of Rheocem in one single hole, even it you have not reached the final pressure.

5 CONCLUSION

The use of Rheocem micro fine grout in these two projects could control the water inflow and meet the requirements to water tightness. The advance rate of the shaft was dramatically increased due to no or minimal waiting times before probe drillings or new drillings could take place 3 to 4 hours after the injection was completed. Compared to normal OPC, the injection of each hole / round was done much faster because to meet the water tightness or stop pressure criteria, less material had to be injected due to the fast setting of Rheocem and therefore a controlled spread of the grout. This leads to a high savings in total costs of the shaft.

With the latest technology improvements (e.g., drilling equipment and Rheocem micro cement grout) it is now possible to specify a target leakage rate, as required, down to 3 to 5 l/min and 100 metres of tunnel, with quite acceptable costs for the pre injection. Properly utilized as part of an overall shaft concept, with savings potential is quite substantial.

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Wiercenia osłonowe i zastosowanie drobnoziarnistego cementu jako środka uszczelniającego spękany górotwór w czasie głębienia szybu

Petrus Johannes Lodewikus Nel, Tom Arild Melbye & Hans Olav Hognestad

Streszczenie: Artykuł omawia zastosowanie wierceń osłonowych, technik uszczelniania i zastosowanie drobnoziarnistego cementu jako środka uszczelniającego wodonośne szczeliny w trakcie zgłębiania szybu do głębokości 3500 m. Istotne znaczenie posiada możliwość wykorzystania stabilnej i niskiej lepkości cementu. Głównym celem cementowania jest efektywne uszczelnienie w jak najkrótszym czasie wszystkich szczelin wodo- i gazonośnych przed ich odsłonięciem zgłębianym szybem. Współczesne metody głębienia nie zdołają zatrzymać zwiększonych dopływów wody a każdy taki dopływ poważnie wpływa na postęp w głębieniu i jego koszt. Żaden inny czynnik nie ma takiego wpływu na wszystkie koszty związane z głębieniem szybu jak czas. Koszty materiałowe OPC przy cementowaniu mogą dochodzić do 5% całości kosztów,

podczas gdy czas przestojów w przeliczeniu na koszt – nawet więcej niż 60%. Większy koszt materiału Rheocem 650 w porównaniu z OPC jest znaczny przy kalkulacji ceny za kg, ale jeśli kalkuluje się czas jest to oczywiście tańsze. Jest to możliwe dzięki właściwościom cementującym Rheocem 650, stosowanego zwłaszcza przy drążeniu sztolni i głębieniu szybu.