

# Stabilization of gravel deposits using microorganisms

## La stabilisation des dépôts de gravier à l'aide des micro-organismes

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### ABSTRACT

One of the techniques used for the construction of underground infrastructure is horizontal directional drilling (HDD). This trenchless method is complicated when crossing gravel deposits as a borehole in coarse gravel tends to collapse, causing the drill pipe to get stuck or the failure of installation of the product pipeline due to exceeding pull forces. In order to find a solution for the problem of borehole instability, the Biogrout process was adapted for borehole stabilization in gravel. In the Biogrout process, loose sand is converted into sandstone by injection of a dedicated mixture in the underground, which stimulates micro-organisms to catalyze chemical reactions leading to the precipitation of calcium carbonate ( $\text{CaCO}_3$ ) crystals. These crystals form 'bridges' between the grains, increasing the strength and stiffness of the material. After a first successful test on lab scale in 2008 in which gravel was cemented, a 3 m<sup>3</sup> container was treated after which a hole successfully was drilled through it using HDD equipment. Following the success of this container test, two field applications were performed as part of the installation of two 48 inch steel gas pipelines with a length of 600 and 900 meter near Nijmegen NL. During these field applications twice a volume of 1.000 m<sup>3</sup> gravel was stabilized in only 7 days each time using the Biogrout technique, after which a HDD was performed successfully.

### RÉSUMÉ

Une des techniques utilisées pour la construction de l'infrastructure souterraine est le forage horizontal dirigé (FHD). Cette méthode sans tranchée est compliquée lors du franchissement des dépôts de gravier que le fluide de forage débusque due à une plus grande perméabilité et l'absence de formation de gâteau de filtration. A cause de l'effondrement du trou de forage, la tige de forage peut se coincer et l'installation de la canalisation peut échouer en raison du dépassement des forces de traction. Pour trouver une solution pour le problème de l'instabilité de forage, le processus Biogrout a (spécialement) été adapté pour la stabilisation de forage dans le gravier. Dans le processus Biogrout, le sable est transformé en grès par l'injection d'un mélange dédié dans le souterrain, ce qui stimule les micro-organismes afin de catalyser les réactions chimiques conduisant à la précipitation des cristaux de carbonate de calcium ( $\text{CaCO}_3$ ). Ces cristaux forment des «ponts» entre les grains, augmentant la résistance et la rigidité du matériau. Après un premier test réussi sur l'échelle dans le laboratoire en 2008 dans lequel le gravier a été cimenté, un conteneur de 3 m<sup>3</sup> a été cimenté après lequel un trou a été foré avec succès à l'aide de l'équipement FHD. Après le succès de cet essai, deux applications sur le terrain ont été effectuées de 600 et 900 mètres dans le cadre de l'installation d'un gazoduc près de Nimègue NL. Au cours du test sur le terrain, un volume de 1.000 m<sup>3</sup> de gravier a été stabilisée en utilisant la technique Biogrout après quoi un FHD a été effectuée avec succès.

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Keywords: Horizontal Directional Drilling (HDD), Biogrout process, *in situ* cementation, biological methods, gravel

## 1 INTRODUCTION

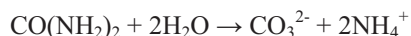
Horizontal Directional Drilling is a method for trenchless and steerable installation of underground pipelines. It enables passage with minimal disturbance of the surrounding areas and/or where application of continuous trenches is impossible or unpractical (Harke Willoughby, 2005). Since the seventies this technique has been used to install pipelines and cables under rivers, canals and major roads. It is applied both in rocks and in soils composed of porous material. When applied in the latter, the stability of the bore hole after drilling is maintained by a viscous and high density drilling fluid (i.e. containing bentonite or xanthane) which aids in stabilization of the bore hole during the initial smaller (pilot) drilling and the reaming phase of the hole to the final diameter, enabling product pipeline passage. The method however is notoriously problematic when drilling in gravel, since coarse gravel tends to collapse, causing the drill pipe to get stuck or the failure of installation of the product pipeline due to exceeding pull forces.

In this paper we describe the adjustment of biological sand-strengthening method –the Biogrout process– as an alternative procedure for the achievement of bore hole stability in gravel. After evaluation of proof of principle, the method was optimized for application of the crossing of gravel deposits near a river in the Netherlands. The procedure was applied in practice prior to the crossing of two 48 inch steel gas pipelines with a length of 600 and 900 meter under the river Waal in Summer 2010.

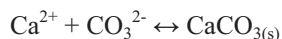
## 2 THE BIOGROUT PROCESS FOR SAND

The Biogrout process has been developed as a method to strengthen sand through *in situ* precipitation of calcium carbonate. In the form most employed, a calcium chloride/urea mixture is in-

jected in the soil after introduction of a suspension of the naturally occurring soil bacterium *Sporosarcina pasteurii* [2,3]. This bacterium is capable of hydrolysis of urea into carbonate ( $\text{CO}_3^{2-}$ ) and ammonium:



The produced carbonate precipitates with the calcium ions to form calcium carbonate



This precipitation leads to an increase in compressive strength, stiffness and tensile strength. The method has been scaled up from 1 L scale in 2004 to 100 m<sup>3</sup> scale in 2008 [4]. In sandy soils, prevention of internal erosion is one of the envisioned applications [5,6].



Figure 1 Cementation of 100 m<sup>3</sup> sand with the Biogrout process [4].

## 3 BIOGROUT FOR GRAVEL: PROOF OF PRINCIPLE

### 3.1 Laboratory tests

It was not immediately evident whether the Biogrout process could be adapted for application in gravel as well. With much less contact points between the individual grains than sand, it was un-

clear to what extent calcite precipitation would aid the strength. A preliminary laboratory program was therefore executed in which 18 kg of gravel was treated with the Biogrout process in wooden boxes. After placement of one pore volume bacteria and subsequent fixation with 50 mM calcium chloride, five respectively nine treatments with 1 mol/L urea/calcium chloride solution (the cementation solution) were applied to induce calcium carbonate precipitation. In the test with nine flushes of the cementation solution, a second batch of bacterial suspension was added after the first five treatments with urea/calcium chloride mixture. In addition, the test with five treatments of cementation fluid was also performed in a system where the gravel was mixed with 1.5 kg coarse sand. After treatment, the boxes were opened on one side and visually inspected (Figure 2).



Figure 2 Gravel after application of the Biogrout process for five (left and middle) and nine (right) flushes. The box in the middle also contained 7% sand.

Calcium carbonate precipitation was visible as a white precipitate on the gravel. It was more abundant on top of the gravel particles than below it, indicating that reaction had taken place mainly within the pore space and the formed calcium carbonate had sedimented by gravity on the gravel particles. The cemented gravel was strong enough to keep its form for several months after draining of the water and removal of one side (as is shown in Figure 2). The absence of a flat top surface and the strong cementation in the bottom rendered the parts however unsuitable for unconfined compressive strength (UCS) tests.

### 3.2 "Container test"

The procedure was subsequently tested on 3 m<sup>3</sup> scale. In this test, two containers were filled with gravel. The first container was filled with a

uniform medium-grained gravel (D50=10 mm, originating from the Moese river near Maastricht (NL)) and the second one containing the same gravel, mixed with coarse gravel (D50=40 mm), as well as with cobble stones up to 300 mm. The tests were performed in Papendrecht (NL) using the same *on site* produced bacteria and cementation solutions as in the 100 m<sup>3</sup> sand cementation tests performed on the same site [4].



Figure 3 Drilling tests in a 3 m<sup>3</sup> cemented gravel container.

Finally, the containers were put in front of a 100 ton drilling rig, which drilled through the entire containers using a 9<sup>7</sup>/<sub>8</sub>" tri-cone rollerbit. This resulted in a stable bore hole inside both containers (Figure 3).

## 4 FIELD APPLICATION

The tests performed at 3 m<sup>3</sup> constituted sufficient proof of principle for the application of the Biogrout process in gravel to proceed with the design and application in the field.

### 4.1 Optimization tests

The number of flushes used for the cementation is directly correlated to the amount of calcium carbonate precipitation, and therefore to the

increase in strength and stiffness. Operationally it is however also correlated to mobilization time as well as materials and operational cost. Furthermore, a too much cemented system will lead to extra power required during drilling, which is not desirable. It is therefore important to find the minimum amount of cementation that will lead to a stable borehole. To that effect tests were performed in boxes with circa 8 kg gravel treated with only one or two flushes cementation solution at concentrations of 0.7 and 1 mol/L. Also in these tests cementation could be observed.



Figure 4 Gravel treated with one or two flushes of urea/calcium chloride in optimization tests.

#### 4.2 Shear box tests

In order to assess whether a physical effect of a low number of flushes with cementation solution was quantifiable, test boxes of 7 kg were produced (similar to those described in 4.1) with 1, 2, 3 or 4 flushes. After cutting (only the wooden box, Figure 5, top), a shear test was performed at a displacement rate of 1 mm/min. The resulting shear stresses were higher with increasing number of flushes, although the residual shear stress seemed to be similar. None-treated gravel resulted in a lower maximum shear stress showing the effect of the process (details in [7]).

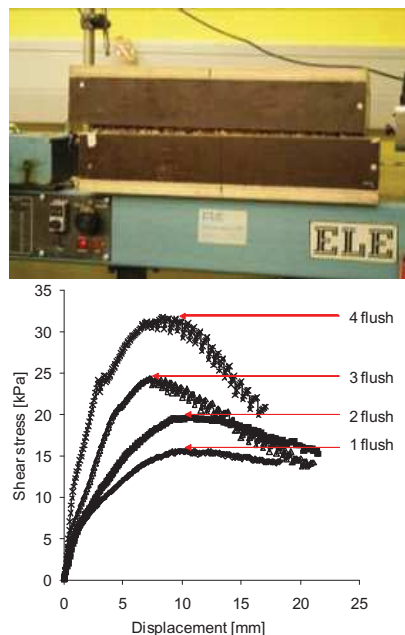


Figure 5 Shear-box tests of Biogrouted gravel (top) treated with various amounts of cementation solution resulted in increased maximum shear stress (bottom).

#### 4.3 Mathematical modelling

Another optimization method was the design of the liquid injection and extraction system. The form of the treated area could not be estimated straightforwardly using Darcy's law analytically because of the threedimensional grid of injection and extraction wells and the potential of gravity driven flow due to the higher density of the injected solution (circa  $1050 \text{ kg/m}^3$ ) compared to the surrounding groundwater. Mathematical modeling was used to evaluate how different injection/extraction strategies and geometries contributed to the shape of the area where cementation took place (Figure 6).

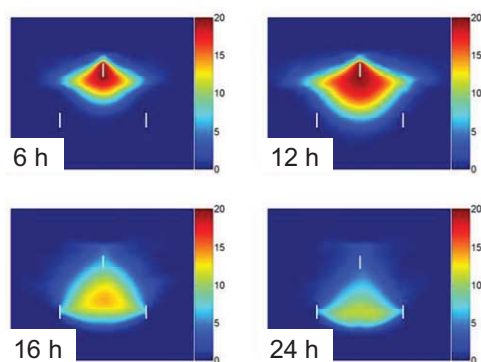


Figure 6 2D model of the treated area during 24 hours. Injection took place at the top and the extraction was performed using the extraction wells placed below the injection wells to both sides.

#### 4.4 Site description of field application

The HDDs at which the Biogrout process was applied were part of the construction of a 48" steel gas pipeline in the east of the Netherlands from Groningen to Maastricht (north-south route). The gas pipeline is part of a program of Gasunie which will improve the capability of the Dutch transmission network to increase gas export at several border crossings. At Beuningen/Slijk Ewijk (near Nijmegen), the river Waal is crossed by means of HDD and when descending during that crossing, several gravel lenses or layers needed to be crossed. At this area these gravel layers were improved with the Biogrout process after which the HDD was executed.

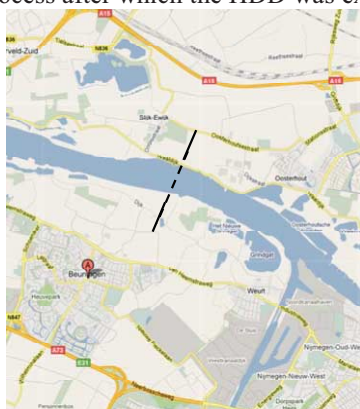


Figure 7 Location of the Biogrouted areas (continuous lines) to enable passing of the river Waal (dashed line).

#### 4.5 Biogrout procedure and HDD

At two different locations along the river Waal, a volume of circa 1000 m<sup>3</sup> was treated with the Biogrout process. In these areas, a single flush of bacteria solution was followed by a single flush of cementation solution. The bacteria suspension (*Sporosarcina pasteurii* DSM33) was obtained from a commercial supplier, as were brines of urea and calcium chloride, which were diluted and mixed on site using a concrete mixer. Injection took place in several injection wells, installed directly above the projected pathway of the pipeline (Figure 8). Extraction wells were placed lower and to the sides. The extraction wells were placed for two reasons:

- to direct the flow most efficiently –and thus economically– to the location where the Biogrout process should take place, and
- to remove the residual product of the process: ammonium chloride.

The removal of the residual product was achieved by extracting 3 days longer than the time needed for the injection of the cementation solution and by extraction at higher flow rates. The extracted water was sent directly to the local wastewater treatment plant, which was able to take the water in its normal operation without further treatment or buffering. The total time involved in stabilizing the gravel layers at one site took about 7 days.

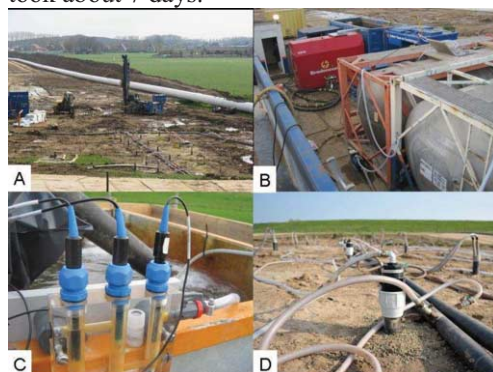


Figure 8 Application of the Biogrout process prior to the HDD: A) the field with injection (middle) and extraction wells; B) mobilization of tanks for calcium chloride, urea and mixing equipment; C) monitoring of the effluent prior to sending to the wastewater treatment; D) An injection/monitoring well.

During drilling and reaming of both HDDs the gravel turned out to be stable and the installation of the two 48-inch gas pipelines using a 450 ton drilling rig were both successful with no problems encountered in the gravel areas (Figure 9).



Figure 9 Installation of the 600 m 48-inch gas pipeline (bottom), using a 60-inch flycutter and 48-inch barrel reamer (top) and a 450 tons drilling rig (middle).

## 5 CONCLUSIONS

With the successful application of the BiogROUT process to achieve bore hole stability in gravel, the biocementation process has for the first time been applied in practice. The application is a suitable risk-reducing measure when drilling fluids are not expected to be able to stabilize the bore hole due to high permeability/no filter caking. Operational and regulatory requirements could be met by extracting the injected liquids followed by treatment. The BiogROUT applications have contributed to a controlled crossing of the river Waal of the North South Route gas line.

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