Assessing the environmental risk of grouting with soft gels

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Abstract: A method commonly adopted for sealing construction pits against groundwater inflow from below is of the installation of deep sealing layers through chemical grouting. In the past 6 years, investigations have shown that practically all mobilisation or subsequent reactions of this type of chemical grouting influence the soil and (contact) groundwater only for a short term and over a very limited area. It can be stated that there are no hazards to soil or groundwater under the conditions, under which the soft gels are used.

Key words: Soft gel, grouting, environmental risk, building material, groundwater.

Introduction

Construction of horizontal grouted diaphragms, which are connected to impermeable vertical cut-offs, are required when excavations extend below the water table and groundwater-lowering techniques cannot be used. Such sealing diaphragms are usually 1-2 m in thickness. Because of the uplift pressure, they must be constructed at a level significantly below the proposed base of the excavation in order to prevent blowouts into the excavation. The design of a successful grouting programme requires the selection of a suitable grout material and the correct drilling equipment, procedures and grout-hole pattern. The most widely used chemical grouts are silicate grouts especially in medium and fine sands. These chemical grouts are true solutions (Newtonian fluids) which contain no suspended solid particles and lack shear strength. Silicate-aluminate grouts are diluted solutions of sodium aluminate (hardener) and sodium silicate. These solutions are able to penetrate fine sands and sandy silts due to their low viscosity.

The commonly applied silica gel has a silica / soda ratio of 3.3 by weight. With the ratio of 2 vol. % sodium aluminate ($Na_2O_m \cdot Al_2O_3 \cdot 18.9\,H_2O$), 18 vol. % filtered silica gel ($Na_2O \cdot (SiO_2)_n \cdot 27.6 \cdot H_2O$) and 80 vol. % water the following chemical reaction occurs (Eiswirth et al., 1997):

$$Na_2O \cdot (SiO_2)_{3.35} + 0{,}17\,(Na_2O)_{1.72} \cdot Al_2O_3 + 1.12\,(H_2O) \rightarrow \quad (1)$$
$$0.01\,Na_{34}(AlO_2)_{34}(SiO_2)_{3.35} + 2.24\,Na^+OH^-$$

Equation (1) elucidates that each mol applied silica gel produces 0.01 mol hydrogel mixture with albitic mineral composition and 2.24 mol caustic soda solution. As a result, the pH values as well as the contents of sodium, silicate, aluminium and organic compounds are increasing significantly in the drainage water and temporary in the adjacent groundwater.

The injection of the liquid gel mixture leads to the displacement of the interstitial water in the subsoil. At places at which the injection solution fills the soil pores uniformly, the gelatinization reaction sets in after the toppling time. The forming gel itself is bound to the soil

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pore matrix adherently and the gel compounds are at first immobile largely (scaffold within the gel grid structure or its pores).
In direct contact with the groundwater, many substances of the initial gel products are released to the subsurface directly after the injection on a short-term basis:

- Caustic soda as disassociated ions Na^+ and OH^-,
- Aluminium (in the present alkaline environment as differently condensed hydroxide-aluminates),
- Silica in the form of differently condensed anionic complexes,
- Small amounts of trace substances (impurities of the gel materials).

CASE STUDY IN THE CITY OF BERLIN

In the City of Berlin, Germany about 100.000 m^3 of silica gels were injected into porous aquifers from 1990 to 1995, because groundwater lowering by dewatering techniques cannot be used for the large excavations due to environmental hazards. The environmental authority of Berlin (SenSUT) therefore insisted in 1995 on investigations of potential groundwater contamination risks due to silica grout injections. After pre-investigations the case study site Ringcenter II, Frankfurter Avenue 111/119, was selected by the Department of Applied Geology, Karlsruhe University (AGK) in order to carry out detailed field investigations over a period of 4 years (EISWIRTH ET AL. 1997, 1998, 1999; SCHNELL, 2001). The soft gel grouting diaphragm was placed into medium to fine sands with a thickness of 1 m at the excavation site Ringcenter II. The excavation site covered a total area of approximately 8,000 m^2.
For Ringcenter II two-dimensional (2D) and three-dimensional (3D) instationary computer model simulations were carried out with the finite element model FEFLOW (WASY GmbH) in order to simulate the potential transport of grouting gel components with the groundwater flow (Figure 1). The results of these model computations under ´worst-case-conditions´ show as expected a considerably larger gel compound flux than under real conditions, prevailing at the excava-

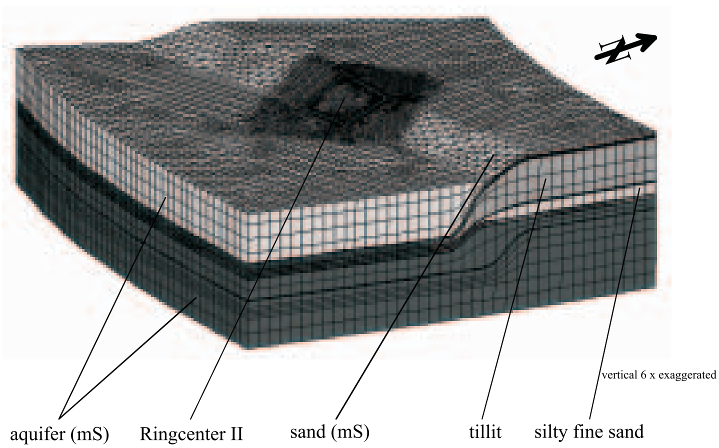

Figure 1. Schematic setup of the 3D groundwater flow and transport model Ringcenter II (OHLENBUSCH, 2001)

tion site Ringcenter II. Without dewatering completely other groundwater flow conditions occur below the excavation that strongly favours a larger gel compound transportation. In this case, parts of the emitted gel compounds could underflow the southern slurry wall of Ringcenter II and reach the downgradient area of the excavation. The concentrations of the sodium-ions would then be just high enough to be identified in the downgradient groundwater observation wells (Figure).

Additionally, the 3D model computations showed that without drainage, the sorption capacity of the aquifer material would not be able to prevent completely a gel compound emission into the environment of the excavation. In this case, however, the gel compound releases would be extremely small and due to the natural concentration fluctuations it would be very difficult to prove their increase at most the groundwater observation wells (Ohlenbusch, 2001).

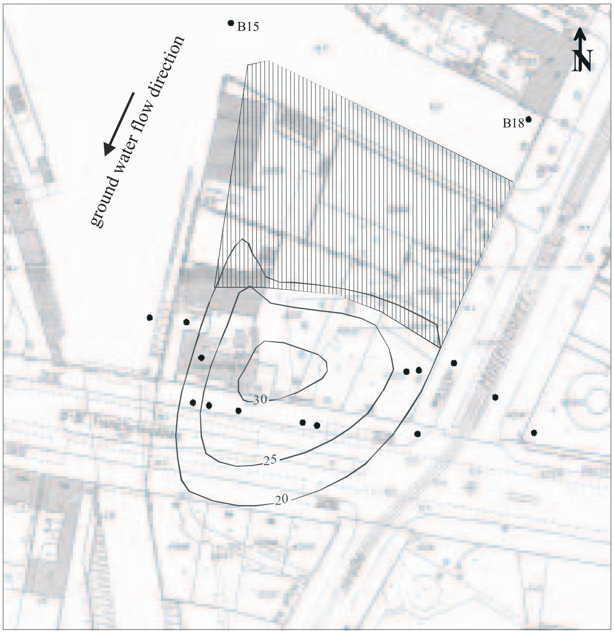

Figure 2. Modelled concentration distribution of the sodium ions [mg/l] at z = 20 m a.s.l. after 365 days since the start of grouting. “Worst-case” assumptions: no flow into the pit and no adsorption effects (Brauns et al., 2001)

Conclusions

The assessment and clarification of the potential risk of silica gel injections on soil and groundwater quality was the central task of the described investigations. The comprehensive evaluation of all laboratory and field data and the results of transport modelling, together with the eco-toxicity tests led to the following overall assessment:

- silica gel injections does not influence the groundwater quality significantly,
- with expert planning and realisation of a silica gel grouting, also the substances mobilized by the gelatinization reaction do not lead to a long lasting or alarming influence of the groundwater quality.

Indeed a silica gel injection leads to the short-term, significant increase of the pH-value in the contact groundwater; however, the described reactions occur very rapidly due to fast neutralization and through continuous buffering within the aquifer. A swift, extensive immobilisation of the before released gel compounds results from that. In most porous aquifers the hydrochemical groundwater reactions downgradient a grouting body will be spatially and temporally very closely limited.
In conclusion it can be stated as well, that the concentration of heavy and trace metals (and for example organic pollutant) decreases significantly from the upgradient area to the downgradient area of a silica gel sealing diaphragm. Responsible for this are for a certain part particular non-reversible sorption processes (mainly surface precipitation). Therefore, a depletion of these components can be frequently found downstream of grouted silica gel bodies. Another statement that must be made is that the silica gel injection stop draped by the SenSUT of Berlin have caused partly negative results both for the environment and for the economy. It the last years in Berlin, during the forced application of alternative construction methods (so-called HDI diaphragms and/or application of cement grouts) many structural problems have been occurred. These problems have been related to the loss of the efficiency (additional financial costs for leakage detection, addition injections, delay costs, etc.) on one hand and unfortunately to negative ecological influences on the other hand (greater groundwater withdrawals during pumping tests to proof sealed diaphragm and wall density). In conclusion, it is recommended again not to keep on discrediting the economical and environmental safe construction method of silica gel grouting.

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