

## GROUNDWATER IMPACT INVESTIGATION DUE TO INSTALLATION OF A "LWS" SILICATE GEL SEALING SOLE IN THE WATER SATURATED SOIL ZONE

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**ABSTRACT.** The present study investigates the effects of the newly developed "BAUER LWS" silicate gel on the water-saturated soil zone on a test site in Berlin, Germany. For this purpose, a project comprising the grouting of a sealing sole of a construction trench has been accompanied by a groundwater sampling and analysis program. Four groundwater observation wells were sampled and analyzed at fixed time intervals over a period of 18 months to monitor changes in groundwater conditions due to the soft gel injection. For comparison with original conditions, a zero measurement has been performed at the beginning of the investigation programme in accordance with the groundwater regulatory framework in order to determine the groundwater chemistry affected by the grouting activities. It has been found, that some of the analyzed parameters showed no response to the gel injection. These parameters were not considered further during the monitoring programme. Other parameters changed significantly during the grouting operations. However, already after the completion of the grouting, all parameters dropped back to their original values. The pH-value of the tested silicate gel was adjusted to an acceptable level of less than 10 in permanent contact with groundwater in order to prevent mobilization processes into the subsoil. The investigation results show, that the injection of silicate gel "BAUER LWS" involves lower substance mobilization than other well established grout material. Therefore, the "BAUER LWS" silicate gel can be applied as environmentally friendly and beneficial grout material in construction projects without expecting large-scale impact on the groundwater replacing alternative substances, such as chemical grouts.

**Keywords:** Grouting, Silicate gel, Sealing sole layer, Water saturated soil, Groundwater, Chemical impact

### ИЗСЛЕДВАНЕ НА ВЪЗДЕЙСТВИЕТО ВЪРХУ ПОДЗЕМНИТЕ ВОДИ СЛЕД ИНСТАЛИРАНЕТО НА УПЛЪТНЯВАЩА ОСНОВА "LWS" СЪС СИЛИКАТЕН ГЕЛ ВЪВ ВОДОНАСИТЕНА ПОЧВА

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**РЕЗЮМЕ:** Настоящото изследване разглежда влиянието на новия силикатен гел "BAUER LWS" върху водонаситени почви в тестово поле в Берлин, Германия. За тази цел проектът включва тампониране на уплътняваща основа на строителна траншея, което е придружено от пробовземане на подземни води и програма за анализ. Взети са проби от четири сондажа за подземни води и са анализирани на фиксирани времеви интервали за период от 18 месеца, за да се наблюдават промени в състоянието на подземните води поради инжектирането на мекия гел. За сравнение с оригиналните условия е направено нулево измерване в началото на изследователската програма в съответствие с регулаторната рамка за подземните води, за да се определи химията на подземните води, повлияна от тампониращите дейности. Установено е, че някои от анализираните параметри не реагират на инжектирането на гела. Тези параметри не са разглеждани допълнително по време на мониторинга. Други параметри се променят значително по време на тампонирането. След приключване на тампонирането, обаче, всички параметри се връщат към първоначалните си стойности. Стойността на рН на тествания силикатен гел се коригира до приемливо ниво, по-малко от 10, в постоянен контакт с подземните води, за да се избегнат процесите на мобилизация в подпочвения слой. Резултатите от изследването показват, че инжектирането на силикатен гел "BAUER LWS" предполага по-ниска мобилизация на веществата, отколкото други добре установени тампониращи материали. Ето защо силикатният гел "BAUER LWS" може да се използва като екологичен и полезен тампониращ материал в строителните проекти, без да се очаква голямо въздействие върху подпочвените води, като се заменят алтернативните вещества, като например химическите тампониращи разтвори.

**Ключови думи:** Тампониране, силикатен гел, уплътняваща основа, водонаситени почви, подземни води, химическо въздействие

### Introduction

In the mid-1990s, the Berlin Senate for Environment banned the construction of grouted sealing soles with aluminate-based soft gel base due to their alleged negative chemical influence on the groundwater. This ban has also been followed by other municipalities and their responsible authorities (especially Water Authorities).

In recent years, the composition of grouting materials has been significantly optimized towards a significantly better environmental compatibility.

Within the construction project "Ringcenter II" designed by Brauns et al. (2001), the chemical influence of the grouting material on the groundwater has been investigated for the first time in detail (BRAUNS et al., 2001). At a construction site of Bauer Spezialtiefbau GmbH in Berlin, Germany, with grouting of a sealing sole in a construction trench, the influence of the grouting process and grouting material on the groundwater quality has been investigated in detail according to the current state of the art.

## Investigation schedule

The present study examined the chemical impact on the groundwater resulting from the installation of a sealing sole in the water saturated soil zone using an "BAUER LWS" silicate gel grouting operation. (The letters "LWS" in the product name stand for the abbreviated initials in the names of its inventors and do not represent chemical components.)

In order to track the spreading of dissolved grout material components, four groundwater extraction wells with different horizontal distance to the silicate gel sealing sole layer have been installed at the project location, one extraction well located in the groundwater inflow and three other extraction wells located in the groundwater outflow area. The depth range of water extraction extended over a 2 meters long filter section installed both above and below the sealing sole layer.

## Project description

The construction trench with an overall surface extension over an area of approximately 3000 m<sup>2</sup> has been created after installing a sheet pile wall along the outer contour line up to a depth of about 15 m to 16 m (see Fig.1 below).

After the removal of a 2m to 3m thick sediment layer mostly consisting of anthropogenic material fill, a working plane has been created and the grouting wells have been drilled. The grouting sealing sole has been created with an average thickness of one meter in a depth of 15 meters below the ground surface. After the groundwater lowering, a residual dewatering has been operated in the construction trench above the grouted sealing sole.

Subsequently, the excavated soil and the concrete floor slab of the building have been installed. After completion of the shell work in the construction trench (below the original groundwater level), the sheet pile wall has been pulled back, exposing the grouted sealing to the regenerating groundwater flow regime.

The groundwater and soil analyses took place over the entire construction period from May 2015 to July 2016. The groundwater extraction wells were positioned outside the construction trench in a depth of approximately 19m. The lower edge of the installed sheet pile walls reached a depth 0.5m below the grouted silicate gel sealing sole layer.



Fig.1. Construction trench during sheet pile wall installation

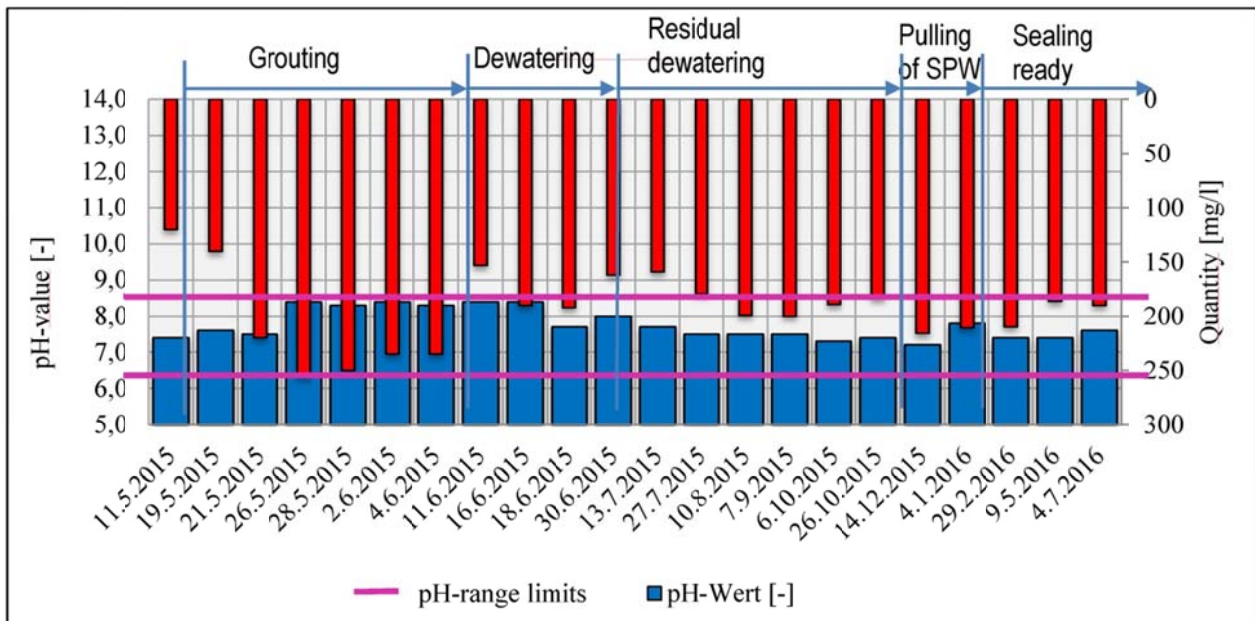


Fig.2. Analysis results at the first groundwater sampling well (GSW1) – pH-Wert=pH-value, Sulfat = Sulphate

Table 1. Analysis result overview for the groundwater sampling wells GSW1 and GSW4

Parameter	Zero measurement	GSW1 (Grouting)	GSW1 (RDW <sup>2</sup> )	GSW4 (Grouting)	GSW4 (RDW <sup>2</sup> )	Eluate analysis E1 (14-16m)	Eluate analysis E2 (16-18m)
pH-value [-] (ALV <sup>1</sup> : 6.5 – 8.5)	7.4	8.4	7.5	7.3	7.1	8.1	8.5
Filterable substances [mg/l] (ALV <sup>1</sup> : 30 mg/l)	< 5 - 110	5130	22,8	11,0	8,0	--	--
Iron [mg/l] (ALV <sup>1</sup> : 2,0 mg/l)	0,33 -4,2	25	1.7	3.0	4.7	0,18	0,065
Sulfate [mg/l] (ALV <sup>1</sup> : 400 mg/l)	120 -240	256	200	367	487	6.9	2.1
Nitrate [mg/l] (ALV <sup>1</sup> : 50 mg/l)	< 1- 2.7	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0

ALV<sup>1</sup> – Admissible limit value; RDW<sup>2</sup> – Residual dewatering; GSW – Groundwater sampling well

### Investigation programme

The effects of soft gel injection on groundwater quality have been observed over a time period of 18 months. In order to document the ground water conditions before the construction measures, a first zero measurement with an extensive analytical programme has been carried out on samples from four groundwater extraction points. A second zero measurement has been carried out after the installation of the sheet pile walls and immediately before the grouting operation has started.

The groundwater samples have been taken from four groundwater sampling wells accompanying the construction and grouting operations. During dewatering of the construction trench, the sampling period was extended to two weeks and during the residual dewatering to two months until the end of the observation in June 2016. In order to measure the chemical impact from the grouting material on the groundwater, the following analytical examination programme has been imposed:

- separable substances, filterable substances
- pH, electrical conductivity
- ammonium



- slightly soluble anions (sulphate, nitrate, chloride)
- metals (cations, iron, lead, chromium, nickel, etc.)
- cyanide, vinyl chloride
- volatile halogenated hydrocarbons (LHKW)
- polycyclic aromatic hydrocarbons (PAHs)
- aromatic hydrocarbons benzene, toluene, ethylbenzene, xylenes (BTEX)
- total organic carbon (TOC),
- dissolved organic carbon (DOC)

Depending on the results during the observation time, the analytical programme has been reduced to the relevant effects. The investigation programme has been adjusted to the construction operation in the trench and has been focussed on mobilization and transport processes in connection with the chemical influence on the groundwater from the grouting.

From the groundwater sampling wells GWS1 and GWS4, two liner soil samples (cores BK1 and BK4) have been extracted. After a sedimentological documentation, the grain size distribution and density have been measured in the laboratory. On two mixed samples from the liner BK1, an eluate test has been carried out in order to determine the potential hazard from leaching out the sand due to the grouting operation.

## Investigation results

### Soil analytics results

Below an approximately 2m to 3m thick local fill, a changing deposit of fine and coarse sands with obvious coal inclusions have been observed in the subsoil up to the investigation depth of 19m.

The heat loss examination of the soil samples has shown values of 0,2 to 2,6% in the sample BK1 and values of 0,2 to 2,3% in the sample BK4 and indicates the organic content that could be potentially mobilized due to the grouting measures.

For the determination of potential pollutants, samples have been taken from different depths in the liner sample cores. With the exception of the increased values for iron and sulphate, the results of the eluate analyses have generally shown a low pollutant content, so that the pollution of the groundwater triggered by the grouting operation measure could be expected to remain within tolerable limits.

### Groundwater analytics results

The investigation results of the groundwater analyses can be readily demonstrated on the results in the inflow area at the groundwater sampling well GSW1 and in the outflow area at the groundwater sampling well GSW4 (see Tab.1).

The mobilization processes of substances influencing the groundwater are primarily triggered by a pH-value in the non-neutral range. The experimental results show, that the pH-value in the examined groundwater remained constant in a range of 6,5 to 8,5 and exceeded the higher limit of 8,5 in only one single measurement (see Fig.2). Although an elevated pH-

value is inevitable in immediate contact with the grouted sealing sole, the investigations point out a strong dilution process due to the groundwater leaving very low potential for possible mobilizing processes around the sealing sole. During the grouting operation, the chemical impact on the groundwater could be kept very low with success.

After the start of grouting, a significant increase in iron and DOC (dissolved organic carbon) concentrations have been observed in the groundwater at the groundwater sampling well GSW1, reaching a maximum iron concentration value of 25.0 mg / l.

With completion of grouting and start of dewatering, the iron concentration in the groundwater has decreased, reaching values in the admissible range. An increase of the iron concentration above the tolerable limit has occurred during the removal of the sheet pile walls from the subsoil. At the end of the observation period, the measured iron concentration values have been in the legally admissible range. Significantly lower changes in iron concentration have been observed on other examined groundwater samples during the investigation period.

As a general result of the investigations on samples from all groundwater sampling wells can be derived that the observed parameters have shown an increased value immediately after the grouting operation, exceeding slightly the legally admissible limit values, returning to values of the zero measurements with increasing time after completion of grouting operations.

The analysis results from the groundwater sampling well GWS4 with larger distance to the grouted sealing sole have shown the slightest changes and due to limited mobilizing processes from the grouting operation. During the observation period, only the iron and sulphate concentrations have shown values exceeding the legally admissible limits. The content on filterable substances has also slightly exceeded tolerable limits, but only at the zero measurements before and thus, independently of the grouting operations.

The parameters of electrical conductivity, ammonium, nickel, cyanide, chloride, chromium, mercury, cadmium, copper, zinc, nitrate,  $\Sigma$ LHKW, vinyl chloride,  $\Sigma$ MKW,  $\Sigma$ BTEX and  $\Sigma$ PAH have always remained below the legally admissible limits of specific water authority regulations during the observation period. Some of the parameters have shown values below the limit of quantification and have been excluded from the investigation campaign.

Furthermore, from the analysis results at the groundwater sampling well GWS4 it could be obviously concluded, that spatial influence by the grouting operation on the groundwater was significantly low and the groundwater impact from grouting has apparently been restricted to the immediate vicinity of the silicate gel sealing sole. Due to dilution effects, obviously a water cleansing process must have taken place.

The analysis results from the last measurement series have shown a decreasing tendency reaching values corresponding to the natural initial groundwater chemistry over time.

## Summary and Outlook

The present study has investigated the impact of a grouting operation with the newly developed "BAUER LWS" silicate gel on the water saturated soil zone at a construction trench in Berlin, Germany. During the investigation period, from the installation of the sheet pile walls until the exposition of the grouted sealing sole to the environment for a long period of time, the groundwater quality has been observed with systematic groundwater sampling and analytical measurements in order to detect changes and influences due to the grouting operation.

It has been observed, that the monitored analysis values have increased significantly during the grouting operations and returned to their initial zero measurement values after the grouting operations have been completed. It has also been found, that some of the observed analysis parameters have not been influenced by the installation of the grouted sealing sole.

The investigations have pointed out that the "BAUER LWS" silicate gel grouting material induces slighter mobilization processes than other comparable, known and practically utilized alternative grouting materials. The adjusted pH-value of the grouting material influences the groundwater and the grouted soil only over a limited time period and only in a limited extent. During contact between groundwater and "BAUER LWS" silicate gel, the pH-value of the groundwater has continuously remained in the upper neutral range.

The groundwater pH-value has been observed within a desired limit value range during the measurement campaign, restricting possible material transport and mobilizing processes to a minimum. The "BAUER LWS" silicate gel can be utilized in construction projects avoiding significant impact on the groundwater, where alternative chemical grouting materials are being planned to be used.

## Conclusions

Despite fundamental improvements with the use of the new "BAUER LWS" silicate gel, there are still plenty of opportunities for further development. Since it has been observed that

substances contained in the soil, especially during grouting, are dissolved and transferred into the groundwater, appropriate approaches are being examined in order to isolate and manage individual solution mechanisms by adjusting the gel properties in order to especially avoid the release of iron and sulphate. Due to the local variation of soil and groundwater conditions on different sites, the subsoil carries different reactive partners or even pollutant substances that could be dissolved and transported by the groundwater and a universal solution for the grout substance recipe appears to be difficult. Furthermore, other undesired side effects and drawbacks have to be excluded, also.

Finally it can be concluded, that with the "BAUER LWS" silicate gel, a well-designed, examined, tested and environmentally friendly grouting material is currently available for practical use.

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