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# Soil fracturing – An injection method for ground improvement

## Sol fracturant – Une méthode d'injection pour l'amélioration des sols

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## SYNOPSIS

Using the grouting method, i.e. the injection of fluid slurries into the voids of the soil, an improvement is achieved with regard to impermeabilization and strengthening. In rock or stiff cohesive soil this grout fills gaps, cracks and fissures and in noncohesive soil the pores between the grains. However, these injections do not disturb the soil structure because fluids are used with low viscosity, which penetrate the voids by relatively low injection pressure. The technology is widely known by many publications and numerous applications.

Contrary to injections, which scarcely influence the structure of the soil, the improvement by soil fracturing is based on the intentional cracking of the soil by the injected fluids. The application is generally restricted to cohesive soils with low permeability, which are not suitable for conventional grouting. The filling of horizontal and vertical cracks with set grout results in

- a supporting network,
- a soil compaction and consolidation,
- intentional heave after saturation and compaction.

Since there are only a few criteria for design, performance and quality control, the application for soil fracturing requires above average knowledge and experience. As examples, the readjustments of two different buildings are presented.

## SEWAGE PLANT DORNBIRN

### Project and Subsoil Conditions

The sewage plant at Dornbirn, Vorarlberg/Austria, was enlarged with a biological-chemical cleaning stage. The chosen area was formerly covered by a swamp. In recent years it was used to deposit garbage and debris. The subsoil is very problematic for any kind of structures because it consists of geologically young and very varying estuary deposits. Up to approximately 10 m depth there are soft to very soft peat and silt-clay layers. Laboratory tests show constrained moduli of generally less than 1 $MN/m^2$.
In the strata below, the organic content is decreasing and sandy-gravelly layers are encountered but the bearing capacity is only slightly increasing with depth. The fine-grained layers between 10 and 20 m depth show constrained moduli of less than 3 $MN/m^2$. The maximum boring depth was approximately 40 m, and no significant change was observed. In addition to the varying stratification, the ground water conditions are also affected to a disadvantage, because there are artesian water tables.

### Foundation and Settlement Behaviour

In view of the bad subsoil conditions, all parts of the sewage plant, including the connecting pipe-lines required special foundations. For the two rather large aeration basins each 80,8 m long and 43,6 m wide the upper soft layers were improved by stone columns. By this process the varying strata were considerably homogenized in order to achieve fairly uniform settlements, induced by the lowering of the ground water table. Moreover stone columns could not possibly fail, because the load from the basin was not in excess of the initial overburden. However, during and after the construction period one of the basins suffered from differential settlements. It was observed that the outer edge - in relation to the entire plant-settled considerably. Especially the corner section, resulting from the arrangement of the expansion joints of the foundation raft had settled in an order exceeding the allowable limit of approx. 4 cm. When re-adjustment measures were started at the end of January 1982, maximum settlement amounted to 73 mm (Fig. 1)

The main reasons for this unfavourable development has to be seen in the following facts. Due to a former real estate border the area was primarily covered with less overburden and thus less pre-consolidated. In addition it was filled subsequently which implied unforeseen load.

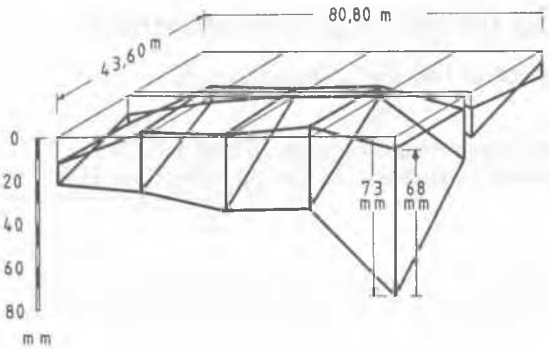


Fig. 1: Schematic graph of the settlement and heave of the aeration basin

## Preliminary Works

The re-adjustment by soil fracturing should not disturb or even destroy a drainage system which had to assure safety against uplift in case of empty basin. Therefore, the stone columns, which normally represent drainage paths, had to be sealed in their upper portions below the drainage and above the soil fracturing injection level. This sealing was performed by jet grouting, which was considered to reach the stone columns even if the borings deviated somewhat. The sealing works included 14 x 3 borings at the frontal edge and 88 x 2 borings alongside (Fig. 2).

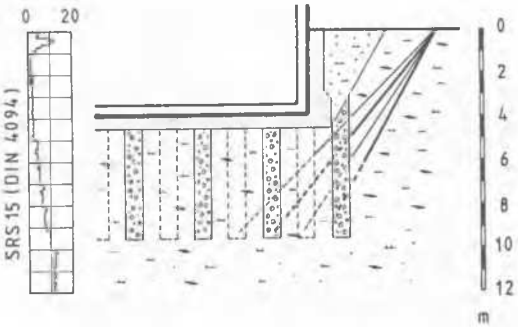


Fig. 2: Scheme of the borings for the sealing of the stone columns including a sounding before the re-adjustment

Altogether approximately 150 $m^3$ grout were injected at a rate of 300 kg blast-furnace cement and 200 kg limestone powder per 1000 l water, stabilized by 25 kg bentonite. It is selfexplanatory that during the jet grouting procedure, as well as during the following soil fracturing works, the drainage system was constantly observed.

## Re-adjustment

The soil fracturing works included 4 x 5 borings at the frontal edge and 11 x 5 borings alongside the basin. These borings were equipped with injection pipes suited for injections at three stages minimum within the lower portion (Fig. 3).

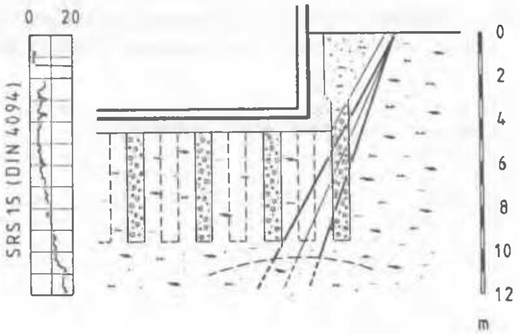


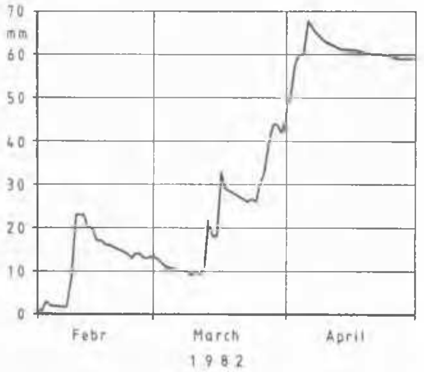
Fig. 3: Scheme of injection pipes including a sounding after re-adjustment

A total of approximately 450 $m^3$ grout were injected at a rate of 400 kg blast-furnace cement and 800 kg limestone powder per 1000 l water, stabilized by 25 kg bentonite. Measurements of heave, inclination of the walls and width of the joints were carefully taken and the quantity of grout was limited accordingly. Due to little overburden and soft soil, the pressures were low except for the immediate bursting of the valves, but sounding before and after the re-adjustment proved to have a compaction effect (Fig. 2 and 3). Undesireable leaking of the grout at the surface were prevented by fast-setting admixtures.

## Conclusions

The soil fracturing process proved to be suitable for the re-adjustment of a large basin of a sewage plant. The works took two and a half months, including all preliminary efforts. At the longitudinal edge of the basin settlements were more or less completely adjusted. The remaining slight inclination of the frontal edges was left to compensate the effect of the filling of the basins (Fig. 1). However, the corner of the basin, which was mainly affected by settlements, was lifted by 68 mm (Fig. 4).

Fig. 4: Heave at the corner of the basin



## VEB BUNA, SCHKOPAU

### Basic Situation

An 18 m high building of a chemical plant, which was erected in 1978 for VEB Buna Schkopau, GDR, suffered considerably from settlements. Mainly affected were nine columns of the steel skeleton structure founded on single footings at different depths. Differential settlements of these footings led to an inclination that endangered the production plant. First steps taken for stabilization consisted of a reinforcement of the steel supports.

### Subsoil Conditions

According to the investigation report and the results of additional core borings the subsoil varies from noncohesive to cohesive layers with partly organic components. Glacial drift immediately below the footings is underlain by loamy gravelly sand and silt to sandy silt with varying content of lignite (Fig. 5).

Aforementioned layers were also tested in a laboratory and the results indicated that the stratification possesses sufficient bearing capacity.

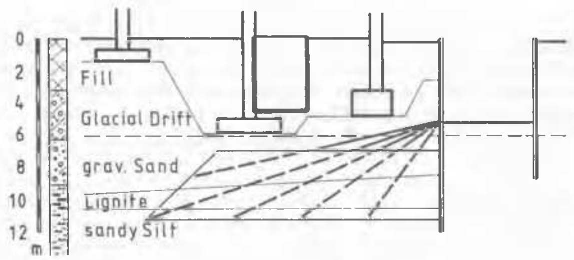


Fig. 5: Schematic graph of the foundation including injection pipes

### Reasons for Settlement

From a broken pipeline an unknown quantity of highly concentrated caustic soda solution seeped unnoticed into the ground. It effected chemical reactions with the lignite which partly led to a nearly complete loss in bearing capacity. The resulting settlements amounted to a maximum of 106 mm at column D-6 before the re-adjustment measures were started.

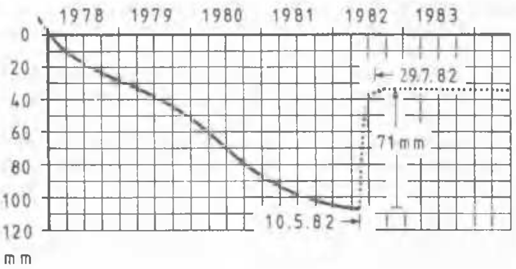


Fig. 6: Settlement and heave at column D-6

To establish adequate measures to improve the subsoil comprehensive investigations were carried out, to include core borings, dutch cone soundings and laboratory tests. They confirmed a remarkable solvent effect on the lignite. The test samples were partly of very soft consistency. The analysed concentration of caustic soda solution amounted to 4 percent of weight. This value was so high that further lignite dissolution could be expected.

### Re-adjustment Measures.

Any measures for solving the problem were not allowed to disturb or hinder, interrupt or even stop the running production process of the plant. Therefore, most possibilities had to be omitted, such as:

soil substitution
mini - piles
pile foundations
pipe protection slabs
jet grouting

Due to low permeability of the strata to be improved even conventional grouting was out of the question. Thus the proposal of GKN Keller to improve the subsoil by soil fracturing was accepted.

### Injection Material

Preliminary qualification tests with customary grouts were performed. They showed that with the prevailing conditions, cement would fail as matrix because chemical reactions would prevent the setting. Therefore the elements of the Joosten-process were used which have been approved for decades. Hereby the setting results from the immediate production of calcium silicate when highly concentrated water glass is mixed with calcium chloride to neutralize remaining caustic soda solution in the soil. In addition aluminium sulphate was injected which also precipitates silicates from the water glass. To enrich the grout with solids, the water glass was admixed with limestone powder at a ratio of 1:1.

### Performance Scheme

Due to many installations and various fittings which should not be distroyed, the work was executed from a ditch 28,5 m long and 5,5 m wide (Fig. 1). Approximately 150 nos. of duplex-injectionpipes were inserted into the area to be treated in a fan-shaped arrangement. The volume of soil was estimated in the order of 1250 m$^3$. Laterally the area was bounded by the sheet pile wall of aforementioned ditch and the remaining bounds were achieved by diaphragm injections which were executed with aluminium sulphate as means for setting and neutralizing. Furthermore an injected cover of approximately 1 m thickness was carried out to avoid uncontrolled fracturing in the vicinity of the footings and to provide an adequate load distribution. Surplus pore water in the soil or from the grout was pumped from relieve and drainage borings which also served as observation holes.

## Performance

The soil fracturing works were carried out with hydrostatic pumps in different stages and passes through the injection pipes. Construction period was from March 10th to August 12th, 1982. The saturation phase was already achieved after few days. After that, position and output of the injection was adjusted to the intended heave of 9 footings within tolerances of 1 to 2 mm. Altogether the columns were lifted as follows:

| Column | 4 | 5 | 6 |
|---|---|---|---|
| B | 12 mm | 8 mm | 3 mm |
| C | 28 mm | 35 mm | 30 mm |
| D | 39 mm | 61 mm | 71 mm |

The maximum heaves were attained at the columns D-4 and D-6 (Fig. 7). At the beginning the heave per shift was approximately 2 mm. This was more and more reduced with growing values.

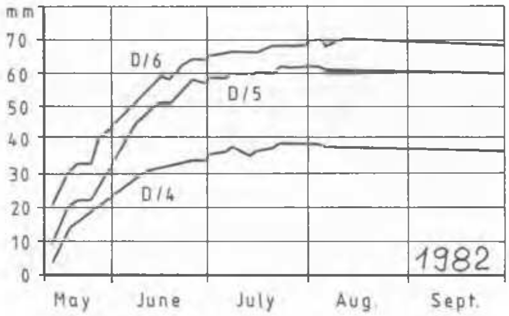


Fig. 7: Heave of the columns in row D

In total the following quantities of grout-materials were injected:

| | |
|---|---|
| 304 $m^3$ | highly concentrated water glass |
| 203 $m^3$ | electrolytical solutions |
| 75 $m^3$ | stone powder |
| 582 $m^3$ | |

With rates of 5 to 15 l/min the injection pressures were 5 to lo bars at the beginning, and at the end, after frequently repeated injection phases, at 10 to 25 bar, depending on the efficiency of the pumps. The pressures to burst the valves and to start the soil cracking increased from 10 to 40 bar accordingly.

## Quality Control

Finally qualification tests were performed. Therefore, 4 core borings were executed with complete core recovery. The visual examination and in-situ tests proved soil-fracturing to be a successful method for treatment in the present case (Fig. 8). Laboratory tests completed the in-situ observations. From core samples the relevant characteristics were determined:

-bulk density
-compressive strength
-moisture content
-remaining alkalinity
-loss-on-ignition

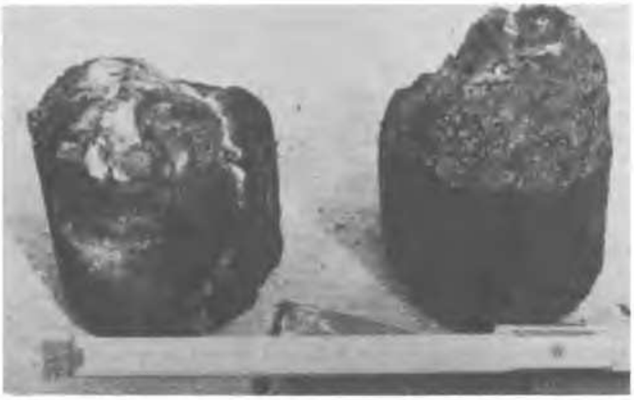


Fig. 8: Cores from the improved lignite

The very soft layers of lignite were drained and compacted so much that the bearing capacity was higher than initially. Furthermore the existence of ramified cracks, filled with set groud, were proved within the cohesive layers and the lignite, forming a permanent load supporting frame.

## Conclusions

Summarizing it can be stated that

- the bearing capacity of the soil was regained,
- all soil characteristics were improved,
- the intended heave was achieved,
- the readjustment will be lasting.

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