Protection of structures with the SOILFRAC® method in the course of two large tunnel construction projects in Germany

Sécurisation d'ouvrages par procédé SOILFRAC® au cours de deux importantes projets d'infrastructure en Allemagne

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ABSTRACT

Using two projects as examples, it will be shown that – based on our extensive experiences made with sometimes difficult soils and often with very extensive building deformation requirements – the technology of the compensation grouting process or SOILFRAC® has asserted itself. In spite of using equipment and control techniques especially adapted for carrying out the work, the use of competent engineers and qualified technical staff remains indispensable. The experiences, particularly those made in recent years, have furthermore shown that this process can be used safely and reliably with very high foundation loads that have slight soil cover.

RÉSUMÉ

En nous appuyant sur deux projets, nous démontrons que le procédé d'injection de compensation SOILFRAC® s'est imposé à partir de nos expériences variées en présence de sols difficiles et présentant des critères souvent exigeants concernant les déformations des ouvrages. Indépendamment de l'utilisation de machines et de techniques spécialement adaptées à la réalisation des travaux, il est indispensable de recourir à des ingénieurs compétents et du personnel de chantier qualifié. Les expériences, en particulier lors de ces dernières années, ont montré que ce procédé peut être également utilisé en toute sécurité et fiabilité dans le cas de charges de fondations très élevées avec une couche de couverture de faible épaisseur.

Keywords : urban environments, Compensation Grouting, SOILFRAC® - Method, various types of soils

1 INTRODUCTION

Higher traffic volume in Germany has made it imperative to improve inner-city infrastructure measures. It is therefore necessary to expand the existing railway system even further to reduce the increasing automobile inner-city traffic to achieve a better utilisation of short-distance public transport. The primary goal of this undertaking is to connect the near environs with the inner cities so that with the short distances involved people can reach businesses, surgeries and cultural events without paying for parking and having to carry their bags for long distances.

The inner-city tunnel tube work is a very large technical challenge in these construction projects. The tunnel construction requirements make it necessary to build tunnel tubes increasingly closer to the upper edge of the terrain. Due to the densely-built inner cities and difficult soil conditions, two large German inner-city infrastructure measures had to be implemented in Cologne with approx. 4 km. of tunnel drilling and in Leipzig with approx. 5.3 km. With some buildings, grouting injection measures helped to accomplish the job.

When working on Leipzig's City Tunnel lot B, it was necessary to implement an active physical safeguarding measure in 33 buildings of the Leipzig city centre by means of the Compensation Grouting process that follows the SOILFRAC® method owing to the forecasted settlements and angular distortions.

In the case of Cologne's north-south line, lot north, extensive grouting injection measures for conserving the existing structural parts were implemented. Due to low covering depths at less the one meter and of the sensitive developments, the soil was improved with the SOILFRAC® method.

2 THE SOILFRAC® - PRINCIPLE

The SOILFRAC® method has been applied successfully by Keller Grundbau for several decades to minimize settlements in connection with tunnelling and to re-level existing buildings.

Packers are installed inside the TAM´s and a defined volume is injected though single valves. This sequence is repeated in several injection phases in order to provide controlled active settlement compensation of buildings, after the contact grouting phase and the pre-stressing of the soil has been completed.

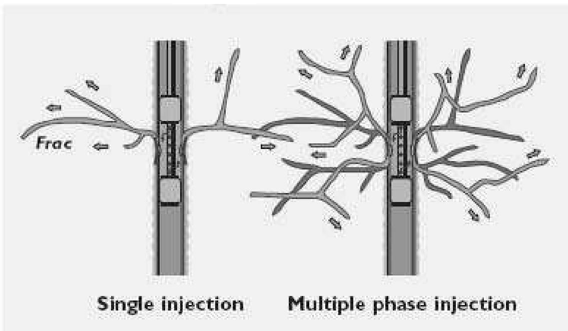

Figure 1: SOILFRAC® - Methode

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3 CITY TUNNEL LEIPZIG, LOT B

The historic, still standing termini of Leipzig Hauptbahnhof and Bayerischer Bahnhof located in the city centre were connected to one another when the tunnel was built. Both tubes of Leipzig's City Tunnel with an outer diameter of 9.00 m and a separating distance of 5.0 m to 10.0 m from one another were created with a tunnel boring machine with fluid- supported drift face. To stabilise the affected 33 buildings whose total area was approx. 22,000 m², about 32,000 m of horizontal drillings were executed up to 8.0 m below the groundwater. The drillings and groutings were done from 15 shafts having a diameter from 3.50 m to 6.50 m. Additional drillings were done inside an abandoned day drift with an inner diameter of 2.40 m in the shopping zone. Due to the unavoidable influence of the environs as a result of the tunnelling work and the fact that many of the buildings were sensitive and under historical protection, and with a minimum distance for the individual structure foundation of just 2.50 m, securing against incompatible deformations was carried out with the Compensation Grouting process.

Figure 2: Working place in the City of Leipzig

3.1 *GEOLOGY*

Leipzig's construction soil demanded more than the usual requirements for executing the drillings because of the geological diversity of the various types of soils, characterized by loose unconsolidated rock and alternate layers of coarse clay, clay, and fine sands with deposits of sandstone blocks having a consistency of up to 240 MN/m². Furthermore, the fillings (especially in the areas of the medieval city moat and the fortifications) were interspersed with building remains and hollow spaces.

Since this critical soil and further conditions of the request for tenders were quite a challenge and demanded a lot from the drilling process, every boring was measured before fitting the sleeve pipes to document their exact location and allow the allocation of the individual valve openings to the building structures.

3.2 *DRILLINGS*

Owing to the cramped working areas, it was necessary to develop and build adapted shaft boring machines for this construction project.

The shaft boring machines had to be built for use in shafts with a diameter of 3.50 m to 6.50 m. Additional client tasks required the execution of bore holes and subsequent injection under covered-up shafts with an entrance opening of max. 1.50 m x 2.60 m or from subterranean garages.

Due to the constraints imposed by the inner-city location, the planning for the execution considered the safeguarding of several buildings from one shaft. To achieve this, it was necessary to create up to 8 superimposed drilling levels with a height difference of 2.50 m. For this reason, the shaft boring machines were capable of flexibly driving over a height difference of 2.50 m with lifting platforms in a very short time. Because of the in-situ groundwater conditions, all bore holes were executed with water stands above the drilling levels of up to 7.00 m with the preventer technology. Understandably, special demands were made on the location accuracy of the bore holes due to the existing buildings. This was the reason that every bore hole was measured with a special probe to check for vertical and horizontal deviations. A drilling method especially adapted to these construction soil conditions could execute most of the bore holes with deviations of max. 1°. The flush drilling process, partly supported by hammers, was used with a special suspension. This special suspension also served as sheathing mixture after installing the 2” steel TAM´s.

The slight settlements measured during the drilling work showed that the applied drilling process – together with the individual work steps – met the requirements made to the drilling work.

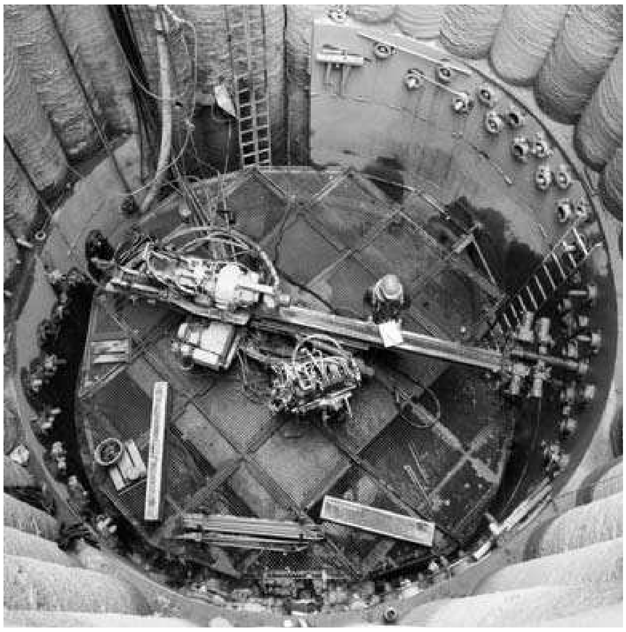

Figure 2: Drilling shaft with diameter 6,50m

3.3 *GROUTING*

Owing to the allowed building deformations already given by the client, it had already been planned to execute injections in various stages for securing the buildings while the tunnelling work was being performed. After completing the drilling work, the contact and uplift grout injection, phase 1 & 2, took place. The contact injection was done to homogenise the subsoil to be worked on and to increase the horizontal tension until a building reaction of approx. 2 mm indicated the structurally effective contact between injection level and foundation. The contact grout injection was followed by the 2nd phase, the uplift grout injection. The basis for the necessary uplifting measures before the shield excavation was the permitted building deformations and angular twists. Owing to the different building structures and the location with regard to the tunnelling, very different uplifting values of up to 11 m had to be set in this phase.

Initial planning had also considered a return movement of the settlements in phase 3 caused by the tunnelling and a grout injection after finishing all tunnelling work (phase 4). Due to the intensive work involved in the contact and uplift grout injections as well as to the optimum setting of the uplifting values, these planned injection phases were no longer necessary. Since the settlements that occurred under the buildings during the tunnelling work were in the order of approx. 5.0 mm, both tunnelling could be executed continuously without incidents.
Regarding building monitoring and for the targeted control of the grout injection work, a pressure hose levelling system was installed in all affected buildings (see Section 5.2).

4 COLOGNE'S NORTH-SOUTH LINE

4.1 *GEOLOGY*

Since Cologne's in-situ construction soil in the area of the injection work consisted of quaternary gravel and sands, the drilling process had to be set up so it would be capable of sinking through existing old sheeting supports and old archaeological installations from Roman times.

4.2 *DRILLINGS*

The bore holes were sunk from a 12-m deep vertical shaft with a diameter of 4.50 m. While doing so, the shaft was created with overlapping jet-grouting columns and a jet-grouting sealing slab, as the working height above the upper edge of the terrain was only 5 m. The maximum drilling lengths were about 50 m, so drilling deviations in the order of approx. 1% could be maintained. Several steel supports could be successfully drilled through, so that every drilled hole could be executed to its planned final length and in the exact position. From this shaft, about 4,000m were sunk and PVC TAM´s installed, later to be driven though by the tunnel drilling machine. The objective of the grouting was to optimally set the support and suspension pressure of the shield machine to prevent deformations in buildings. A ramification and luting of the soil structure (SOILFRACTURING) had to be achieved in the process.

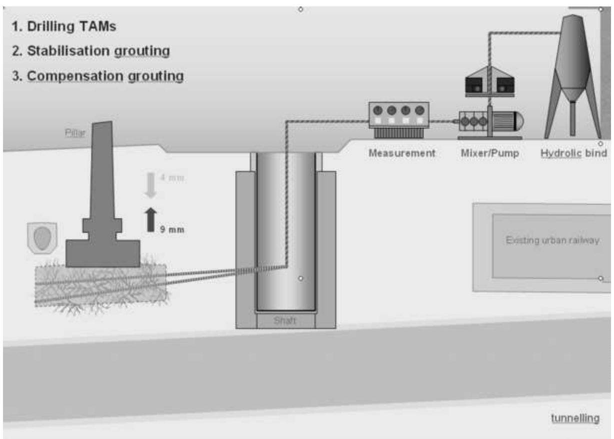

Figure 3: Drilling and Compensation Grouting

To do this, the tunnel drilling machine sometimes went through several buildings where the distance separating the lower edge of the foundation and the tunnel ridge was no greater than 1 m.

The shaft drilling machine had to be capable of sinking bore holes both horizontally and vertically – in other words, drilling starting points were available both in the shaft wall and in the shaft bottom.

Another task was to lay a sleeve pipe shelf made of steel TAM´s from a higher location, approx. 2.50 m above the shaft bottom. This injection shelf had the task of securing a suburban railway pillar for subsequent tunnelling.

4.3 *GROUTING*

The grouting for the tunnelling work were completed in up to 5 phases, in which the grouting parameters such as pressure and quantity were continuously evaluated. The objective was to achieve a uniform pressure level and with it, uniform tension conditions in the soil to create optimal conditions for the subsequent tunnelling work. The grouting measure ended after a uniform pressure level over the entire injection area was recognizable by evaluating all grouting parameters. Photos of the tunnelling work taken later showed an almost perpendicular sloping wall of the in-situ soil within the grouting area (see Fig. 4).

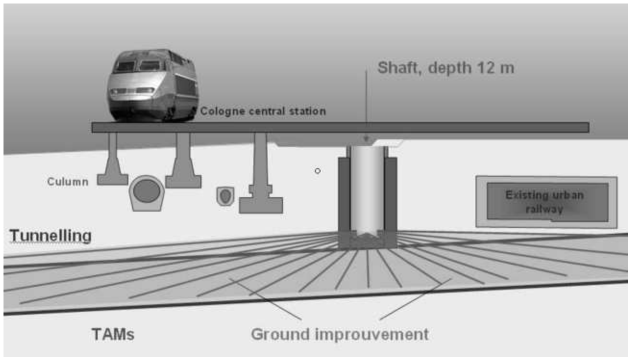

Figure 4: Ground improvement for TBM

The uplift grouting injection of the individual support was done in several injection phases. Pressure hose levelling instruments helped to recognize the strict demands made on the total deformation (+- 5 mm). The individual support, which had been driven under in vertical fashion by the subsequent tunnelling work, was lifted by about 5 mm so that it could experience the settlements of up to 10 mm caused by the tunnelling work. The support could be lifted uniformly and precisely to 5 mm. During the tunnelling work, the individual support settled 5 mm, so it was placed back to its original position.

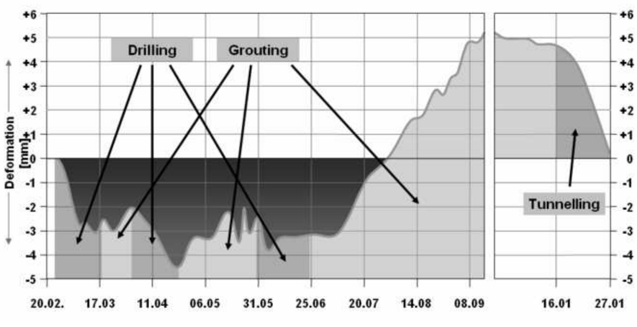

Figure 5: Deformation line of the pillar

5 QUALITY CONTROL

5.1 *BORE HOLE MEASUREMENT*

When the final depth was reached and complying with certain requirements, the drillings in the drill column were measured with a bore hole module probe MAIBOHR II of the reflex type. The measurement accuracy of the optical measuring probe used was 0.08%. Based on the results of the measurement, the planning for subsequent measure control or possible necessary additional drillings was updated.

5.2 *HYDROSTATIC LEVELLING SYSTEM*

When uplifting grouting injections take place, it is absolutely necessary to recognize promptly with the observation method the deformations of the buildings to be secured. For this reason, both projects used hydrostatic pressure hose levelling instruments that worked automatically. They were installed in the buildings or structures that had to be secured. The hose levelling instruments are capable of measuring deformations continuously. The measuring accuracy of the pressure hose levelling instruments is +/- 0.2 mm.

5.3 *SUSPENSION CONTROL*

So the work described herein could be executed professionally and reliably, it was also necessary to test the quality of the used drilling and injection equipment to ensure the same quality. Some important quality characteristics of this are the composition of the suspension or base material, the testing of properties such as density, degree of settlement and development consistency.

5.4 *GroutControl®*

All drilling and grout injection data as well as measuring data are collected and saved in data carriers. To assess injection success, all data must be put in one place and analyzed, taking the temporal and spatial contexts into account. This can be done with a graphic visualization, among other methods. The complete documentation and evaluation of all important data is done for monitoring successful work and at the same time constitutes the basis for accurate work.

In view of the large quantity of collected data, only efficient IT-supported systems can process it in construction practice. To accomplish this and for reporting purposes, the injection software GroutControl® is used.

6. CONCLUSIONS

The experiences of the last decades with the protection of structures, particularly in the con text of tunnelling and in a difficult foundation with very far-reaching requirements on uplifts precision as well as its control, have lead to the fact that SoOILFRAC® technology has gained world wide acceptance. Last but not least, these successes result from the further development also in the area of the measuring and surveillance technology

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