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Underpinning of a historical foundry hall in a complex subsoil in Ingolstadt, Germany

Soutènement d'une fonderie historique dans un sous-sol complex à Ingolstadt, en Allemagne.

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ABSTRACT: Built in the 19th century, the foundry hall in Ingolstadt is designated as a listed building. The hall will be converted into the Museum of Modern Arts by meeting the requirements of a contemporary building but preserving its structure and historical significance. TREVI is involved in an essential part of this project, which focuses on the execution of micropiles for the underpinning construction.

The hall was built in several stages and founded on various layers of archeologically valuable fortifications and moats used from the 16th to18th century. The remaining structures made of limestone masonry, concrete and wood can still be found within the whole construction site in depths ranging from 2 m to 12 m. Consequently, the variability within the foundation and the subsoil was barely predictable beforehand.

Performed micropile load tests showed discrepancies of shaft friction values within the construction site. The interaction between above mentioned anthropogenic remains and the natural soil seems to cause these differences.

Within a drilling depth of 17 m all layers from the 16th to 19th century were perforated. Drilling in wooden materials with a common drill bit did not prove feasible. Instead, custom-fit drill bits were designed, with the ability to cut through the wood and drill through the natural soil and masonries with a consistent quality.

This paper will highlight the challenges facing structural as well as execution and equipment related requirements in a complex building ground in order to retrofit the historical building into a modern museum.

RÉSUMÉ: Construit au XIXe siècle, le hall de la fonderie est classé monument historique. Tout en conservant sa structure et son importance historique, ce hall a été transformé en musée d'art moderne en répondant aux exigences techniques d'un bâtiment contemporain. TREVI a participé à une partie essentielle portant sur le forage de micropieux pour la construction du mur de soutènement.

Le hall a été construit en plusieurs étapes: il est érigé sur diverses couches de fortifications et de douves ayant une importante valeur archéologique. Les structures qui demeurent encore dans le sol varient sur l'ensemble du site et se trouvent à des profondeurs allant de 2 m à 12 m; elles sont composées de calcaire, de béton et de bois. Par conséquent, la variabilité à l'intérieur de la fondation et du sous-sol était à peine prévisible préalablement.

Les essais de charge sur micropieux effectués ont révélé des écarts dans la capacité de charge à l'intérieur de la zone de construction. L'interaction des vestiges anthropogéniques profonds sus-mentionnés avec le sol naturel semble être à l'origine de ces différences.

Sur une profondeur de forage de 17 m, toutes les couches du 16ème au 19ème siècle ont été perforées. Pour pallier le problème des forets sur mesure, possédant la capacité de couper le bois et de percer le sol naturel et les maçonneries avec une qualité constante, ont été conçus.

L'article soulignera les défis auxquels font face les exigences en matière de structure, d'exécution et d'équipement dans un terrain de construction imprévisible.

Keywords: underpinning; micropiles; heritage building; load testing; customized drill bit

1 PROJECT OVERVIEW

The historical foundry hall is situated at the sidelines of the medieval downtown of Ingolstadt, Germany. Built in 1885, it was part of the royal Bavarian artillery and the bullet foundry until 1919.

Hence the historical significance of the more than 130 years old building lies within its former dominant function as a leader for the economic and technical development as well as a main employer in the region.

Figure 1 Computer graphic of the new Museum of Modern Arts (Querkraft Architekten ZT GmbH, Wien)

Besides the economic and social value, the building, more accurately its subsoil, is also of high archeological significance. The subsoil contains a layered system of various former structures used from the 16th to18th century.

To integrate the historical meaning of the foundry hall into the everyday life of the modern society, the municipality of Ingolstadt has decided to convert the abandoned hall into the Museum of Modern Arts. The new design of the Museum incorporates the open exhibition room 4,5 m below the ground.

To execute the new lower level, the underpinning of the foundry hall is necessary. The team of structural and geotechnical engineers set up a design to implement the ideas of the architects. Due to limitations for construction in and around the protected building and the complex subsoil, different alternatives for the underpinning were evaluated. Eventually micropiles for foundations were chosen.

The foundry hall has a base area of around 1.500 m². The drilling depth of the micropiles reaches up to 17 m. The selfboring micropiles are constructed with a hollow steel bar with an outer diameter of 103 mm and a drill bit of 175 mm diameter.

The opening of the Museum of Modern Arts is scheduled for 2020.

2 CHARACTERISTICS OF THE SUBSOIL AND THE HALL

2.1 Composition of the subsoil

The construction site is located about 300 m north of the Danube river. Consequently, its natural subsoil formation and groundwater system is strongly influenced by the river.

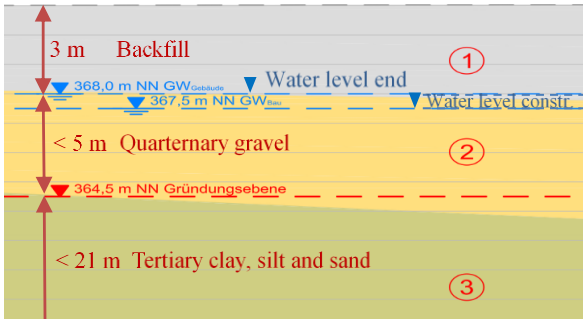

Figure 2 Geological profile (adapted from Werkraum Engineers, Vienna)

According to the geological report the dominant geological formation belongs to the upper fresh water molasse which consists mainly of fine-grained sediments. The natural formation consists of alternating mostly clay and silt layers with intermediate sandy layers. These tertiary sediments are covered by a thin (< 5 m) layer of quaternary gravel and around 3 m of backfill (see Figure 2).

Two existing groundwater horizons are found. The first horizon is approximately 3 m below the surface in quaternary gravel and unconfined. The second groundwater horizon lays in the tertiary sand layer, around 10 m below the ground surface with its pressure as high as the quaternary one.

As the hall was founded on various layers of former town fortifications and surrounded by moats used during the Renaissance and the Baroque in the 16th to 18th century, the remaining structures made of limestone, concrete and wood embedded into natural soil stratas can be found within the whole area of the construction site in depths up to 12 m. Figure 3Figure 2 shows the assumed structure and composition of the moat and the different materials used.

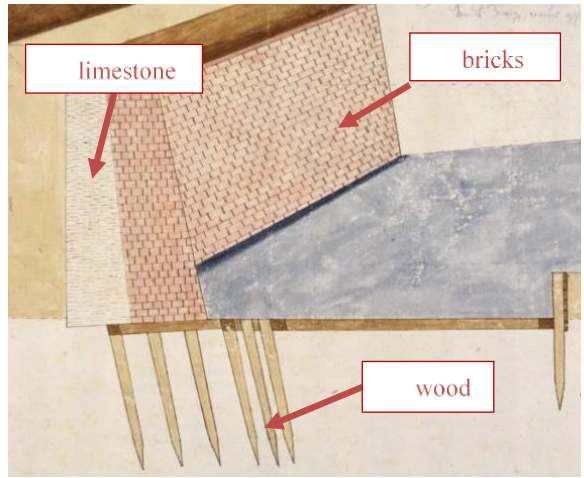

Figure 3 Assumed structure and composition of the moats (adapted from Werkraum Engineers, Vienna)

Additionally, foundations of the machines used in the foundry hall in the 19th century are still remaining in the upper part of the subsoil. Thus, the composition of the subsoil and therefore the drilling characteristics were hardly predictable beforehand.

The remains of high archaeological significance as in Figure 4 are carefully uncovered and documented in the course of the project by archaeologists.

Figure 4 Wooden remains within the subsoil

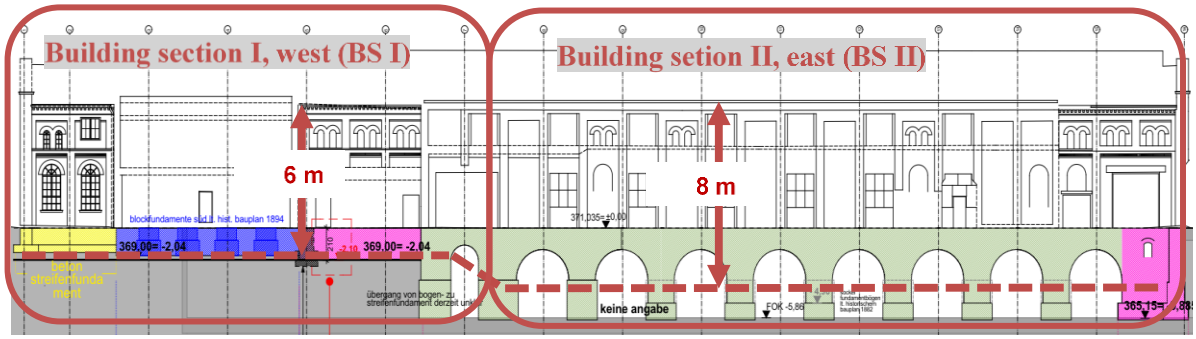

Figure 5 Display of the hall with its building sections and working heights (adapted from Werkraum Engineers, Vienna)

2.2 The foundry hall

The foundry hall in its present appearance was built in various stages. Therefore, existing foundations of the hall vary not only in their geometry, but also in their depth. Figure 5 shows that the western part of the hall was founded on raft foundations (about 2 m deep) and the eastern part was founded on arch foundations up to 6 m depths. Due to static reasons like e.g. the risk of bearing failure, the working platform for the execution of underpinning in the western section (BS I) had to be situated higher than the one in the eastern section (BS II). This leads to a limited working height of approximately 6 m in BS I and 8 m in BS II as depicted in **Error! Reference source not found.**, what is considered as one of the most challenging limitations for the execution of underpinning.

Additionally, as the façade of the foundry hall is more than 100 years old, the underpinning must be carried out with as little vibration as possible.

3 CONSTRUCTION OF THE UNDERPINNING SYSTEM

Due to the ancient remains in the subsoil and the undefined material composition of the façade, special requirements are set to the underpinning system. One of the requirements is the ability to drill through natural soil layers and the remains such as masonry and wooden piles with a consistent quality of execution. Also, the used system must cause little vibration during production and contain a low potential of deformations.

For above mentioned technical reasons initially the execution of bored piles was suggested. However, due to the limited working height in BS I, the use of piling equipment for large diameter bore piles is not feasible. The working height of 8 m in BS II, allows the execution of bored piles, however it is considered as a challenging task.

Alternatively, a micropile tripod was designed. The typical for this project tripod is depicted in Figure 6. Each tripod replaces a single bored pile. Because of the lower carriage of the drilling rig this solution was feasible even in the section with working heights of less than 6 m.

3.1 Design of the micropile tripod

System Ischebeck self-drilling micropiles (hollow steel bars) with an outer diameter of 103 mm using the rotary percussive drilling method is applied in this project. The length of the micropiles varies between 12 m and 17 m. The drill bit with a diameter of 175 mm is used.

The bridge-like construction is designed to transfer the loads of the building over steel crossbeams into a deep foundation on both sides of the façade. The upper part of 3 m to 6 m is excavated to build the new basement. After the construction of the new basement is finished, the upper part of the micropiles will be removed.

As the upper part of micropiles will be uncovered during the excavation of the new basement (see Figure 6), special attention is set to the bending and buckling resistance of the underpinning system. Therefore hollow steel bars with an outer diameter of 103 mm were used. Additional stiffening levels planed to be installed every 2 m in the tripod, providing sufficient stiffness through various stages of execution.

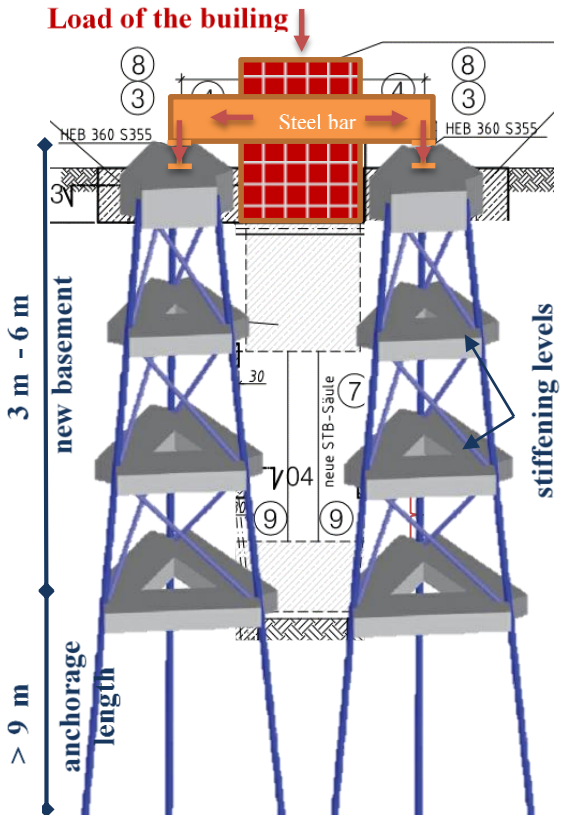

Figure 6 Typical construction of the tripod with self-drilling micropiles and stiffening levels (adapted from Werkraum Engineers, Vienna)

3.1.1 Test drilling

To gain further information about the interaction between the remains, the natural soil and the drilling tools, TREVI decided to perform test drillings prior to the production. The most crucial aspect is to find the right drill bit in order to perforate the natural soil and the masonries as well as the wooden piles with the constant quality and performance efficiency.

The use of percussion drilling in wooden materials with a common drill bit did not prove itself as feasible in former projects. Therefore, custom fit drill bits had to be prepared on site which are able of ripping the wooden structure and drill through the natural soil as well as the masonry.

The best results were achieved by customizing common carbide drill bits with four carbide chisels (see Figure 7). Thus, for the execution of the micropiles those customized drill bits are mainly used in parts where the wooden piles are assumed to be.

Figure 7 Customized drill bit with carbide chisels

3.1.2 Micropile load tests

Initial values of the shaft friction were derived from former load tests of ground anchors from several construction sites surrounding the found-

ry hall. To verify the predicted soil parameters and respectively the shaft friction values in this complex subsoil, micropile load tests were executed. Throughout the project area seven test micropiles close to existing exploratory drillings were executed: 3 micropiles in BS I and 4 in BS II (locations shown Figure 8). The test piles were executed in the exact same way as the underpinning piles. The load tests were executed according to the EA Pfähle, DIN EN 1997-1 and DIN 1054. The test load P_P was approximately $2*P_c$ (characteristic load) and varies between 500 kN and 800 kN (where P_c varies between 250 kN and 390 kN).

Results of the load tests showed a significant difference in the load bearing capacity of the micropiles between BS I and BS II. All three test piles in BS I achieved at least the required test load P_P whereas in BS II the required test load P_P could not be achieved on any of the tested piles. Despite the extensive results from anchor load tests performed in surrounding sites, the shaft friction values of the micropiles for BS II could not be estimated with a sufficient accuracy.

Results of the load tests indicate~~s~~ highly variable and thus complex subsoil conditions. The assumed reason for those results is the wider than initially expected extent of the remains in the subsoil. This assumption was reaffirmed by the collected evidences during the drilling of the micropiles and the partial exposure of the remains by archaeologists afterwards. Initially only around 3 % of the drilling line was expected to contain remaining structures. But during the construction phase it became clear that around 25 % of the drilling line contains remaining structures, reaching down to approximately 12 m.

Figure 8 shows the locations of historical remains, initially assumed by archaeologists. Based on the results of the pile load tests, BS I is less influenced by man-made structures than BS II. This conclusion corresponds well with the initial estimations made by archaeologists.

3.2 Redesigning of the underpinning system

Based on the updated information about the complex subsoil, the tripods for BS II must be adapted to the challenging subsoil. Since the applied self-drilling rotary percussive system ha~~s~~ already reached its limits due to the combination of the clayey soil at a drilling depth of up to 17 m, an increase of the micropile length was not considered a reasonable solution. At the same time, an increase of the external load-bearing capacity by increasing the diameter of the drill bit was assessed as impracticable, as the second largest available bit with a diameter of 175 mm was already in use.

Therefore, further alternatives for the underpinning system are considered:

- The use of post grouting;
- Drilling off steel bars in previously installed jet grouting columns;
- Construction of bored piles in BS II.

In order to finish the project in time, it was decided to produce BS I with the initially planned micropile tripods. Meanwhile the alternative underpinning design for the BS II can be developed taking into account the experience and knowledge about the underground gained from the execution in the BS I.

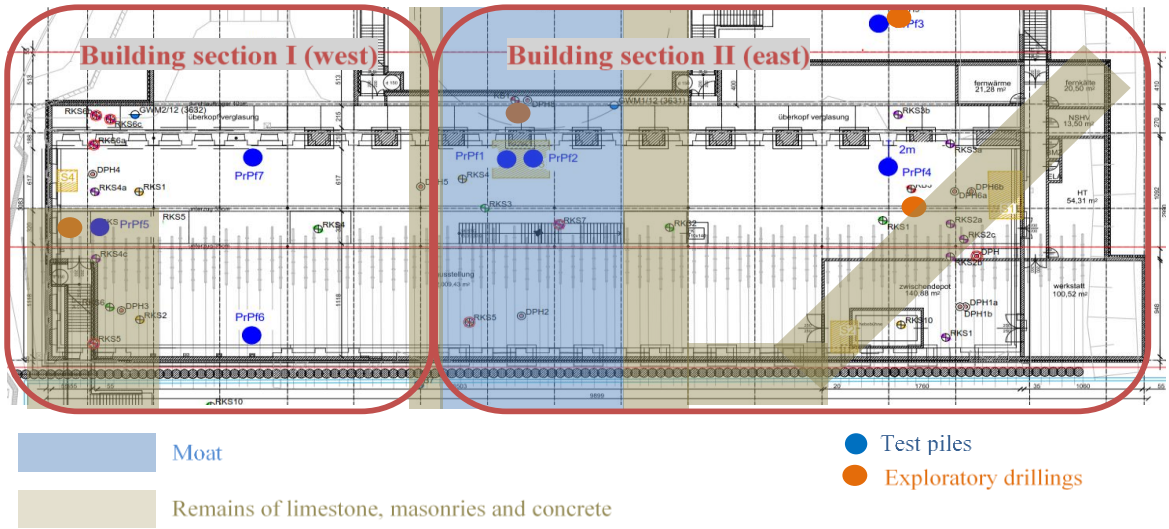

Figure 8 Overview of the location of the test piles, exploratory drillings, remains and moat (adapted from Werkraum Engineers, Vienna)

4 CURRENT PROJECT STATUS AND PERSPECTIVE

As this paper is being written the construction works on site and the final design of underpinning in the BS II is still in progress focusing on advantages and disadvatages of in the section 3.2 mentioned alternatives.

As one possible alternative to self-drilling micropiles the use of post grouting is considered. Experiences show that the shaft friction of post grouted micropiles can achieve 20% to 30% higher valus.

Large diameter bored piles offer sufficient reserves of the load bearing capacity in variable soils and thus are considered as a safer option. However, the limited working height up to 8,0 m in the BS II will restrict the execution.

Because of all circumstances described in chapters 2 and 3 the most effective design for the underpinning in BS II has not yet been developed.

5 CONCLUSIONS

The experiences gained in this project show that foundation engineering faces the challenge of having only selective information about the subsoil. The results derived from the exploratory drillings are the groundwork for design of the underpinning system in a complex subsoil.

To take up such challenge and be able to derive reliable planning data from a small amount of information, pile tests are of particular relevance in strongly inhomogeneous subsoils. They guarantee the quality and safety of the underpinning.

However, considering discrepancies between the expected and the actual extend of the remains, it becomes clear that an initial estimation of soil properties must be verified and adjusted in the course of the project as knowledge increases. This applies in particular to a strongly anthropogenically altered subsoil such as the one described in this paper.

So far, based on the results of the test drilling and micropile load tests, the team of TREVI and design engineers were able to find the right ge-

otechnical solution by executing micropiles as tripods. Moreover, the specifically for this project developed custom drilling bit allowed to achieve the constant execution quality despite the presence of various remains in the natural soil. Hence, all requirements to the design, the execution and the quality of foundations provided by both complex, inhomogeneous subsoil and the listed heritage foundry were met for BS I.

6 ACKNOWLEDGEMENTS

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