TREVI S.P.A. FRANKFURT FOUR

FOUNDATION DRILLING

AUGUST/SEPTEMBER 2020

UMA
LARGE SOIL NAIL WALL

ADSC
2020 SAFETY AWARD WINNERS

BAUER/ECA
SEMI-AUTONOMOUS DRILLING UNIT

BRAUN INTERTEC
EXPOSED DRILLED SOLDIER PILES

LEE & SIMS
DRILLED SHAFTS FOR A SOUTH CAROLINA BRIDGE

ADSC
The International Association of Foundation Drilling

18 TREVI S.P.A.

FRANKFURT FOUR – CONSTRUCTION SITE AND FOUNDATIONS FOR FOUR SKYSCRAPERS IN THE HEART OF FRANKFURT BANKING QUARTER

COVER STORY

FRANKF

FIGURE 1: VISUALIZATION OF FOUR TOWERS (GROSS & PARTNER, 2017)

URT *four*

CONSTRUCTION SITE AND FOUNDATIONS *for four* SKYSCRAPERS *in the heart of* FRANKFURT BANKING QUARTER

BY
FLORIAN KAINEDER & LARS KÜNNEMANN

FIGURE 2: FRANKFURT CLAY WITH AN EMBEDDED LAYER OF LIMESTONE (23,0 - 24,15 M)

INTRODUCTION

In the heart of Frankfurt's banking quarter, on the former location of Deutsche Bank (Bank of Germany), the spectacular skyscraper complex is considered one of the largest building sites in Germany, with an area of approximately 16,200 m^2. After completion, four skyscrapers, with heights up to 228 m, will rise above the common base construction, a ground slab at a depth of 20 m below the ground level. Within the area of 205,500 m^2, the complex will accommodate more than 600 apartments, social infrastructure, hotels, multiple restaurants and the highest office space in Germany (Figure 1).

TREVI S.p.A. – Zweigniederlassung Deutschland was commissioned by GP Con GmbH, a daughter company of Groß & Partner, to execute the retaining structure by means of a diaphragm wall and to complete the foundation works.

GEOLOGICAL AND GROUNDWATER CONDITIONS

The project area is located within the Mainzer basin on the north edge of the large-scale tectonic rift structure of the Rhine valley rift.

Beneath man-made deposits at ground level lay quaternary sediments of fluvial terrace and aeolian silt deposits and tertiary sediments – Hydrobia layers from the Miozen, also known as Frankfurt clay, which consist of clays, sands, gravels and limestones (compressive strength *qu* up to 400 kN/m^2, Figure 2). Below the Frankfurt clay is the Rüssingen formation (Frankfurt limestone), underlain by the rocky Cerithium beds.

In addition to the upper groundwater horizon of water-bearing quaternary sands and gravels, the second groundwater horizon under artesian pressure lays in the tertiary stratum – sands and fissures in limestone.

The water table for the construction phase is defined at 94 mNN (4 to 7 m below the ground level).

EXECUTED WORKS

Pre-drilling

Despite extensive demolition works, the removal of all existing constructions and old retaining structures – specifically reinforced concrete walls and ground slabs along the site boundaries and below the groundwater table – was not achieved. Therefore, pre-drilling along the diaphragm wall axis was required prior to the execution of panels. This was achieved by means of approximately 570 vertical and 14 10° inclined boreholes with a diameter of 1,500 mm and lengths up to 10 m.

FIGURE 3: GROUND SLAB ENCOUNTERED DURING THE PRE-DRILLING

> *A double-shell safe wall from Deutsche Bank made of reinforced concrete with steel bars of 36 mm was encountered in a particularly challenging section along Große Gallusstraße."*

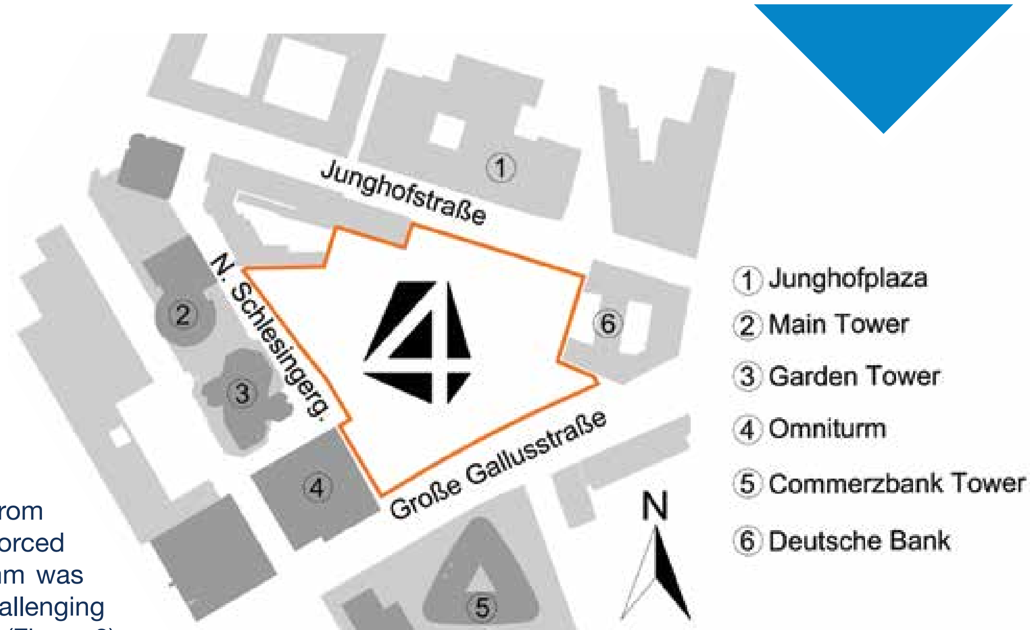

FIGURE 4: LOCATION OF THE PROJECT SITE WITH ADJACENT BUILDINGS

A double-shell safe wall from Deutsche Bank made of reinforced concrete with steel bars of 36 mm was encountered in a particularly challenging section along Große Gallusstraße (Figure 3). The pre-drilling in this section was demanding for both personnel and drilling rigs. A drilling capacity of only 5 meters per day was achieved.

To prevent bentonite losses and to achieve positive results in static calculations for the stability of the trench, the sequence of low-pressure injections (4250 m of boreholes, 346,000 l of injected slurry) was executed in the upper inhomogeneous layer of backfill.

Construction of excavation pit

Due to the central location and the resulting limited space (Figure 4), the top-down method with two horizons of bracings and ground anchors in several sections was applied to support the excavation pit.

The retaining structure, which secures the excavation pit from the inflow of groundwater and acts as the water retention system, is completed in the first construction phase. Then, the ceiling above the basement is concreted and it functions as the first horizon of bracings. Since the width of the ceiling is more than 100 m, it is additionally stabilized by 231 primary columns, which transfer loads from the ceiling during the excavation and structural loads from the building in the final construction state to piles.

"Originally planned as a secant pile wall, a 1.2 m wide diaphragm wall was proposed by TREVI as an alternative."

Originally planned as a secant pile wall, a 1.2 m wide diaphragm wall was proposed by TREVI as an alternative. The maximum panel length is roughly 45 m and the circumference of the diaphragm wall is approximately 550 m based on the ground plan.

In addition to two grab units, the use of the hydromill trench cutter was required to minimize vibrations, resulting from excavation of very hard, in places more than 2 m thick limestone layers (Figure 5). Therefore, the application of the cutter successfully reduced vibrations and related damages to adjacent buildings.

Bored Piles

Both foundations for the common base construction and for four skyscrapers are designed as combined piled raft foundations (CPRF).

372 foundation piles were executed from the uniform working platform at 96 mNN. Drilling depths up to 45 m with empty bores of roughly 17 m were reached (Figure 6). Bored piles of varying diameters – 1380 mm, 1680 mm and 1860 mm – were executed as partially cased, slurry-supported piles and were equipped with pipelines for geothermal energy.

Primary columns

The majority of the primary columns are designed as precast, reinforced concrete elements with cross-sections up to 1 m x 1 m (weight up to 40 tons). These columns must meet the highest installation tolerances because the additional cladding is not foreseen in the final construction state.

FIGURE 5: SOILMEC SC-135 HD WITH THE CUTTER SH-40

FIGURE 6: EXECUTION OF PILES WITH SOILMEC SR-125

Besides, a small number of steel columns is planned, which serve as temporary supports for the ceilings and will be removed in the final state of construction.

EXPERIENCES FROM THE EXECUTION

Diaphragm wall
Despite extensive underground exploration provided by the client, the actual thickness, frequency and conditions of limestone layers remained largely unknown prior to the execution of the diaphragm wall. To mitigate geology-related risks, the previously provided soil investigation was extended through additional underground exploration drillings. These drillings were located on the axis of the diaphragm wall at 25 m intervals.

The applied combination of two diaphragm wall grabs and the cutter allowed to successfully manage this challenge. Through a careful planning of excavation sequence, the use of one cutter for two grab units proved to be sufficient.

The design and position of the upper edge of the guide wall had to be adjusted to highly variable load bearing underground conditions along the diaphragm wall axis. This resulted in height differences of the guide wall of up to 4 m between adjacent diaphragm wall panels, which caused additional complications for the planning of the construction sequence.

> “DESPITE EXTENSIVE UNDERGROUND EXPLORATION PROVIDED BY THE CLIENT, THE ACTUAL THICKNESS, FREQUENCY AND CONDITIONS OF LIMESTONE LAYERS REMAINED LARGELY UNKNOWN PRIOR TO THE EXECUTION OF THE DIAPHRAGM WALL.”

FIGURE 7: OVERLAP REINFORCEMENT

The regulation of Frankfurt Lower Water Authority envisaged a retaining structure in a staggered manner to eliminate the groundwater retention in the periphery of the construction site. As such, panels were executed in alternating long/short sequence.

However, due to high loads, the static capacity of short panels could not be fulfilled without excessive forces being transferred into long panels through joints. To meet this requirement, an overlap reinforcement in joints was provided (Figure 7). This solution led to significantly reduced installation tolerances and simultaneous on-site planning of assembly and installation processes, adjusted on measured deviations.

Manufacturing and installation of primary columns

Due to varying static loads, lengths and cross-section dimensions, about 140 different designs were utilized for 231 columns. The concreting of precast columns with a high degree of reinforcement up to 850 kg/m3, a complex formwork geometry, as well as a number of built-in parts (Lenton sleeves, lifting openings) significantly complicated the manufacturing process.

The complex auxiliary steel construction was developed by TREVI to install columns in the piles (Figure 8). The installation starts after the drilling of a pile is completed and the reinforcement cage is placed in the borehole:

1. The refence unit is placed on the casing, aligned and tightened by screws.

2. A quiver, shaped as a bottomless rectangular steel pipe, is set on the reference unit and fixed on the casing.

3. The punch (“Jungfer”) is attached to the column´s head.

4. A column is lifted from a horizontal to a vertical position by two cranes via two steel spindles. Once a column is in a vertical position, the load is transferred from the steel spindles to the puncher.

5. The punch with a column is lowered into the quiver. Internal dimensions of the quiver (length about 10 m) correspond to external dimensions of primary columns. In this way, the quiver determines the position and orientation of primary columns and prevents a reinforcement cage from being damaged.

6. The punch is located on the reference unit and its proper level is adjusted by a set of lifting screws.

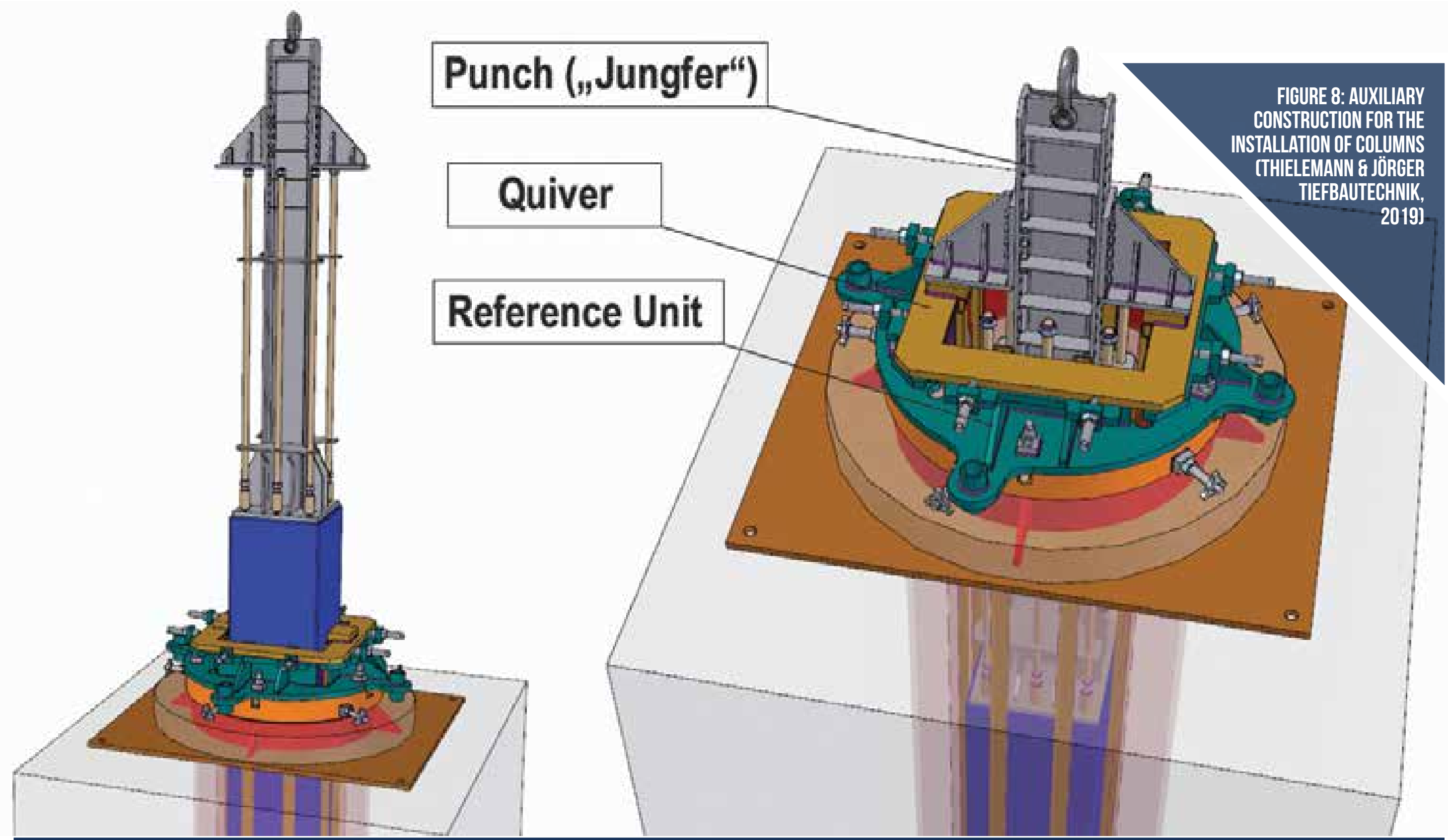

FIGURE 8: AUXILIARY CONSTRUCTION FOR THE INSTALLATION OF COLUMNS (THIELEMANN & JÖRGER TIEFBAUTECHNIK, 2019)

The concreting of the pile is carried out between the adjustment of the auxiliary construction and the installation of the column.

Logistical situation

In addition to limited space in the city center, further logistical complications were caused by other large-scale construction projects in the vicinity, such as facade works on the adjoining "Omniturm" or on "Junghofplaza" (partial demolition and reconstruction of a 35 m high building).

To avoid interference with the neighboring construction sites as well as public transport, the coordination of up to 200 vehicles a day was required. The delivery of oversized items (reinforcement cages, columns, machines) was mainly carried out during the overnight hours.

Despite a site area of about 16,200 m^2, space-related problems were faced through the course of geotechnical works. At the beginning of the project, demolition works were still carried out parallel to foundation and diaphragm wall works. The situation was worsened by the presence of extensive construction site facilities, 11 machines (up to 220 t each) at peak times, storage spaces for primary columns, reinforcement cages and drainage of excavated material.

CONCLUSION

The Project Frankfurt FOUR is currently considered one of the largest construction sites in German-speaking countries. Its size and complexity have contributed to multiple technical and logistical challenges faced through the course of the executed works.

It should be emphasized that the partnership-based cooperation with the client enabled the implementation of technical know-how in the execution of drilling and diaphragm wall works and preservation of the construction schedule.

Lastly, through careful planning and effective application of diaphragm wall technology, TREVI proved that, from both technical and economical points of view, the execution of diaphragm walls is possible in the bank quarter of Frankfurt.

project TEAM

Peter Hofer | Lars Künnemann | Anja Lippert
Andrea Manetti | Jochen Massner | Tiberio Minotti
Rudolf Moherndl | Christian Piaggi | Andreas Pomianek
Renata Sousa | Lorenzo Taverna | Marija Zagoniajeva