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An innovative dewatering system to reduce the environmental impact

Un système d'assèchement innovant pour réduire l'impact environnemental

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ABSTRACT: Frankfurt's highest office floors are being built on 16 000 m² within downtown Frankfurt. On top of 4 underground floors four new high-rise buildings, reaching heights of up to 228 metres, are constructed on combined pile-raft foundations. The depth of the excavation pit reaches 20 m into the Frankfurt clay and 16 m into the groundwater. To construct the underground floors the top-down technique with a surrounding diaphragm wall is planned. An innovative well system to reduce the energy level of the confined groundwater is planned. This dewatering system regards different construction phases by using different depth of wells as well as the foundations piles as tension piles. The aim of this innovative system is to reduce the amount of extracted groundwater and to reduce the environmental impact. Furthermore, all foundation piles and the diaphragm wall are going to be equipped by a closed tube system to use shallow geothermal energy.

RÉSUMÉ: Les étages de bureaux les plus hauts de Francfort etons construits sur 16 000 m² au centre-ville de Francfort. Au dessus de 4 niveaux en sous sol, quatre nouvelles tours d'habitation, allant jusqu'à 228 mètres de haut, sont construites sur des fondations combinées pieux et radiers. La profondeur de la fosse atteint 20 m dans la terre glaise de Francfort et 16 m dans la nappe phréatique. Pour construire les niveaux de sous-sol, on a planifié la technique top-down avec une paroi moulée périphérique. Un système de pompage innovant pour réduire le niveau énergétique de la nappe phréatique confinée est prévu. Ce système d'assèchement concerne différentes phases de construction en utilisant une profondeur différente de puits ainsi que des pieux de fondation comme pieux de pression. Le but de ce système innovant est de réduire la quantité d'eau extraite de profondeur et de réduire l'impact environnemental. De plus, les pieux de fondation et la paroi moulée vont être équipés d'un système de tubes clos pour utiliser l'énergie géothermique peu profonde.

Keywords: top-down technique, dewatering, confined groundwater, diaphragm wall

1 PROJECT

The 16.000 m² large developing area of the Deutsche Bank Areal (Four) in downtown Frankfurt consists of 4 high-rise buildings within 4 basement floors. The surface terrain is about 100 meter above the sea level (m ASL). The excavation pit reaches a depth of approx. 20 m (79.5 mASL). The project works started in 2017 with the demolition of the existing buildings. The pit and foundation works are planned to start in 2018. The essential specifications of the new development are given in the following table.

Table 1. Project data

Parameter	
excavation pit depth	ca. 20 m
Tower 1:	
Footprint	1600 m²
Height / floors	228 m / 57
Tower 2:	
Footprint	825 m²
Height / floors	173 m / 48
Tower 3:	
Footprint	1100 m²
Height / floors	120 m/ 32
Tower 4:	
Footprint	1150 m²
Height / floors	100 m / 25

Figure 1 shows a visualisation of the project.

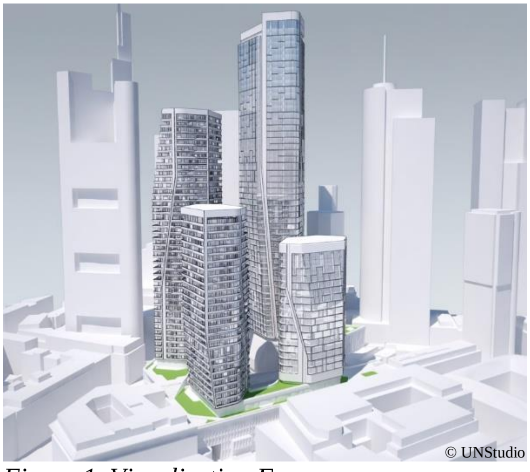

Figure 1. Visualisation Four

2 SOIL AND GROUNDWATER CONDITIONS

The ground conditions within the project area were investigated by 15 boreholes with length up to 170 m. The encountered ground consists of fillings, quaternary sand / gravel followed by the Frankfurt clay which was formed 2 to 10 million years ago as a result of the sedimentation in the Tertiary sea. The Frankfurt Clay is interbedded by limestone banks and layers of calcareous sand. The clay is geologically overconsolidated through older, already eroded sediments.

Beneath the Frankfurt Clay rocky inflata and cerithia layers defined as Frankfurt Limestone are situated. The Frankfurt Limstone is composed of massive limstone and dolomitstone layers, algal reefs, sand, silts and marl clay. Although the Frankfurt Limestone is heterogenous and cavernous it is a strong and stiff formation in comparison to the Frankfurt Clay. The schematic soil model is illustrated in fig. 2.

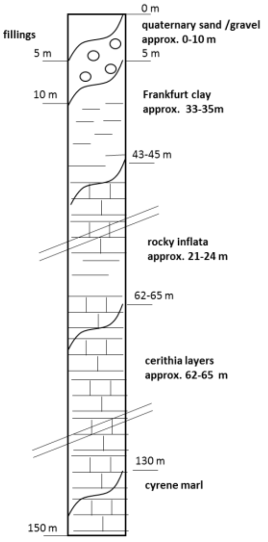

Figure 2. Schematic soil model

The first groundwater level in the quaternary sands is approximately 3 m to 5 m below ground surface. The second groundwater level is perched and circulates in the fissured limestone banks and sand lenses. The energy level of the perched groundwater level in the Tertiary reaches the level of the quaternary groundwater level.

The layers of the quaternary sands and the tertiary sands and limestone are pore aquifers. The limestone banks and Inflates are joint or karst aquifers.

If there is no anthropogenic influence, the quaternary groundwater flows from the north as well as from the south to the Main as a recipient. The groundwater direction of flow and the hydraulic routeing can be changed, e.g. by surrounding subway tunnels or other existing buildings.

Considering the long-time measurements, the following groundwater levels can be defined.

Table 2. Design water levels

Groundwater	level
construction time retaining wall considerations	94.0 /93.5 m ASL
construction time uplift considerations	94.0 m ASL
maximun level	95.0 m ASL

3 FOUNDATION AND RETAINING SYSTEM

All external boundary conditions, including soil and groundwater conditions, loads, adjacent above-ground and underground structures as well as the requirements for stability and serviceability must be considered for the foundation, retaining and dewatering system.

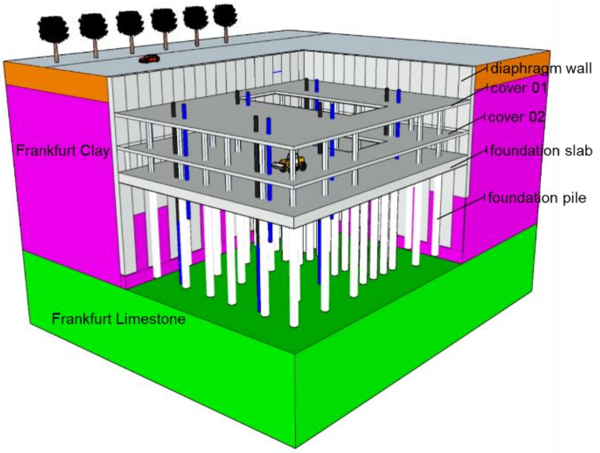

Figure 3. Top-down technique

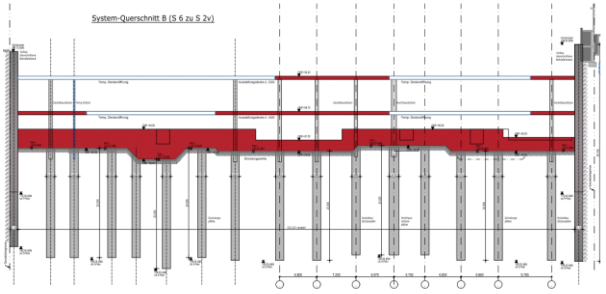

Figure 4. cross-section of the project

The foundation system which was chosen in this case, is a combined pile raft foundation (CPRF) with a total of approximately 377 foundation piles. The load transfer of all structural loads takes place via the foundation piles as well as via the bottom slab.

The dimensioning of the CPRF was done by 3D-Finite-Element simulations. The following figures shows the constructive elements and a result plot of the deformations in the numerical model.

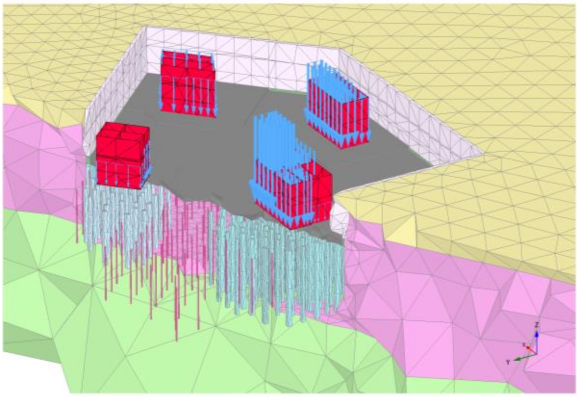

Figure 5. Numerical model - Constructive elements

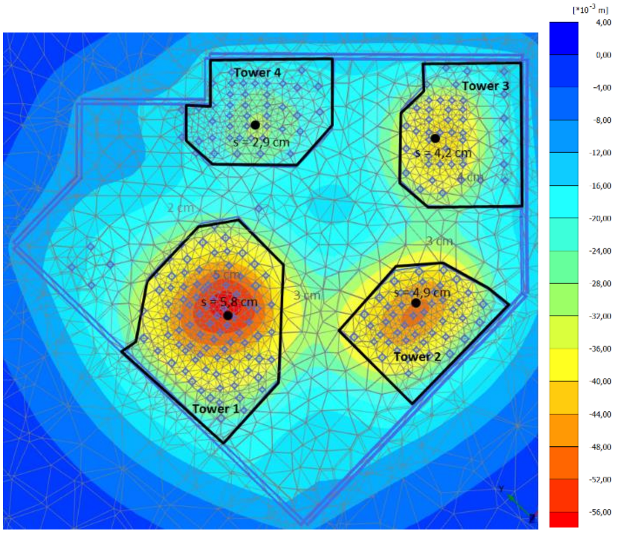

Figure 6. layout – Settlements of the towers

4 EXCAVATION PIT

Basically, the construction of the basements is performed under the protection of a quasi-impermeable excavation pit. The surface area of the excavation pit amounts to approx. 16,000 m², the circumference amounts to approx. 550 m. The bottom of the excavation is at 79.20 m ASL, which means 20 m below ground surface and approx. 14 m below the groundwater level.

A diaphragm wall (d = 1.2 m) is planned to secure the excavation pit. The diaphragm wall is braced with 2 floor slabs.

The shorter panels of the diaphragm wall reach down to a maximum depth of 72 m ASL, whereas the longer panels reach down to 60 m ASL considering the static proofs of stability and serviceability.

The idea of shorter panels within the diaphragm wall is to reduce the water pressure on the wall. Each second panel is planned to be shorter, so only the residual water pressure (fig. 7) must be regarded for the stability calculations of the diaphragm wall.

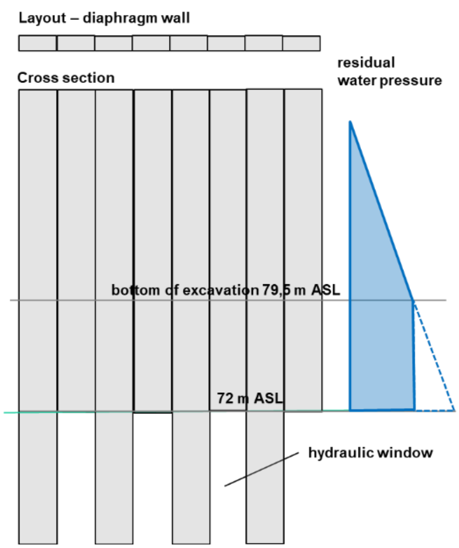

Figure 7. Residual water pressure

5 DEWATERING SYSTEM

The lowering of the groundwater consists of the lowering of the phreatic (free) groundwater level within the quaternary layers and the lowering of the energy level of the confined groundwater within the interbedded layers of the Frankfurt Clay.

The lowering within the quaternary sand without a complete closure of the retaining wall was not allowed by the authority (formerly planned as phase 1). All planned wells must be drilled from a level higher than the groundwater level.

The groundwater dewatering is planned with different types and lengths of wells. Subsequently, the excavation pit is drained in a multi-phase process which is described in more detail in the following text.

5.1 Dewatering phase 2

The diaphragm wall is completed and the excavation is down to floor slab 01. Within the diaphragm wall the quaternary groundwater level is lowered to 92.20 m ASL. Only the wells of phase 2 are active. All deep wells of phase 3 and phase 4 are inactive (fig. 8).

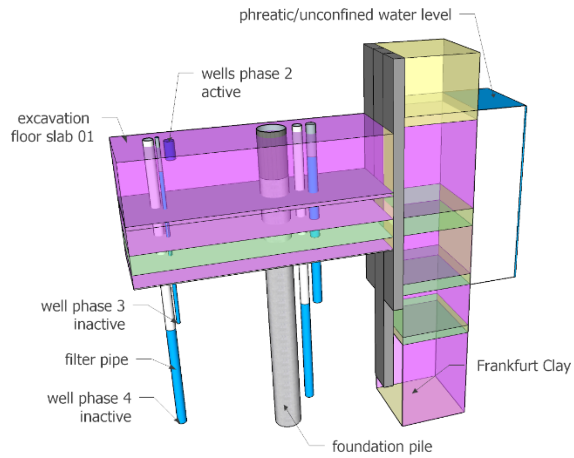

Figure 8. Dewatering phase 2

5.2 Dewatering phase 3

The excavation goes down to floor slab 02. The wells of phase 3 are active in order to reduce the water uplift forces on the temporarily excavation level.

The length of the wells of phase 3 is driven by the proof of uplift forces. The required depth of these wells is a little shorter than the depth of the shorter panels of the diaphragm wall, so that the dewatering only takes place within the quasi-impermeable retaining wall. There is no dewatering outside the pit in phase 3. This aspect leads to an optimization of extracted groundwater.

The wells of phase 3 are planned up to a depth of approx. 74 m ASL and only in every second well a water pump is installed. The required diameter of theses pumping wells reaches approx. 620 mm. All other wells of phase 3 are planned with a diameter of only approx. 150 mm (vertical drainage). The extracted water in these vertical drainages is going to flow within horizontal drainage system on the bottom of every excavation level to the pumping wells of phase 3 (fig. 9).

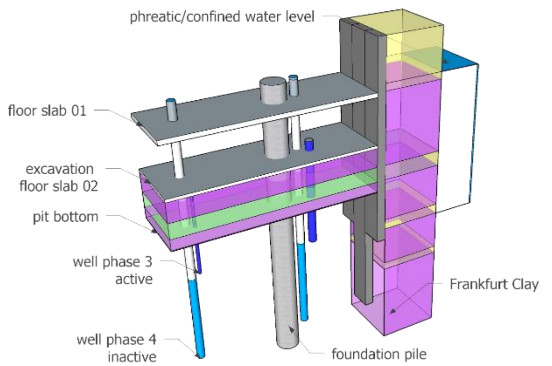

Figure 9. Dewatering phase 3

5.3 Dewatering phase 4

The excavation goes down to the bottom slab (final excavation level). The wells of phase 3 and phase 4 are acitve in order to reduce the water uplift forces on the temporarily excavation level. The wells of phase 4 must reach down to approx. 60 m ASL. All wells of phase 4 are installed with pumps (pumping wells). There is no hydraulic connection between wells of phase 3 and phase 4 allowed. Therefore, the wells of phase 4 have a relatively long solid pipe, only the part below the wells of phase 3 receive a filter pipe.

The wells of phase 4 reach below the quasi-impermeable retaining wall, hence there is for some period of time an unavoidable lowering of the confined water level outside the project site.

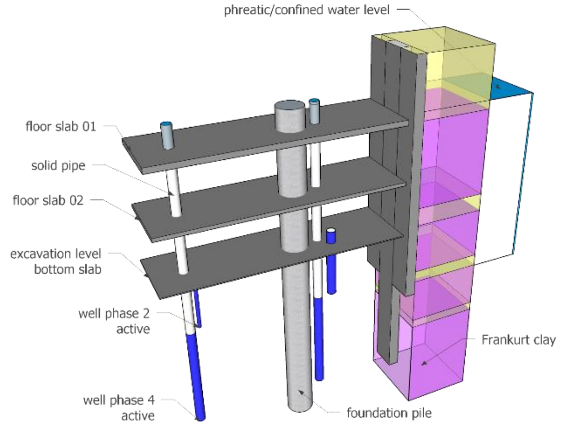

Figure 10. Dewatering phase 4

5.4 Dewatering phase 5

As soon as enough construction weight (bottom slab, walls, etc.) is reached, the wells of phase 4 are deactivated and backfilled. Now, only the wells of phase 3 are active. In order to deactivate the wells of phase 4 as quickly as possible the foundation piles act as tension piles, so that the proof of the buoyancy is fulfilled.

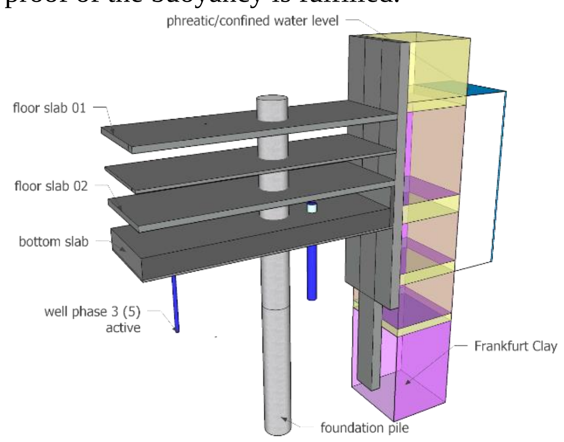

Figure 11. Dewatering phase 5

6 EVALUATION OF EXTRACTED GROUNDWATER

The extracted groundwater of phase 2, phase 3 and phase 5 was evaluated under respect of the quasi-impermeable retaining wall. Due to the horizontal layering of the Frankfurt Clay, it is assumed, that a vertical groundwater flow is negligible. The intake of groundwater into the excavation pit results only through the system-related residual permeability of the diaphragm wall. This residual permeability is derived from the differential water level in and outside the retaining wall as wells as from the ground conditions.

The amount of extracted water of phase 4, where the active wells are below the quasi-impermeable retaining wall, is decisive for the whole dewatering. The amount was derived from realized dewaterings of comparable projects in Frankfurt [2].

Table 3. extracted groundwater and flow rate

Phase	extracted groundwater	flow rate
2	ca. 25,000 m³	12 m³/h
3	ca. 55,000 m³	25 m³/h
4	ca. 1,600,000 m³	200 m³/h
5	ca. 220,000 m³	45m³/h
total	ca. 1.9 mio m³	-

Without the optimization of different phases and different length of wells the extracted groundwater can be estimated to approx. 3.3 mio m³. The planned optimization leads to a reduction of 1,4 mio m³ extracted groundwater.

7 MONITORING PROGRAM

The effects of dewatering on the environment and the hydrogeology is monitored by 100 groundwater measuring points within a radius of approx. 1,000 m around the planned excavation pit. Six month before the beginning of the construction of the diaphragm wall the monitoring starts on a monthly basis and will be intensified to weekly measurement while dewatering. The quality of extracted groundwater is controlled by weekly chemical analysis.

The retaining wall as well as the neighbouring structure are also going to be monitored by topographical surveys and geotechnical measurements.

8 CONCLUSIONS

Under respect of various boundary conditions such as stability and serviceability considerations, constructability, authority regulations and cost considerations all project participants must interact in a very close way in order to obtain an optimised retaining and dewatering system. On the basis of an extensive ground investigation and a detailed description of the ground, the retaining wall and the dewatering system of a 20 m deep excavation pit can be planned in an economic and safe manner. The choice of the adequate retaining and dewatering system is strongly depending on the interaction between retaining wall and well length in order to optimise the amount of water and to minimize the hydrological impact.

By carrying out a monitoring system it is possible to verify the assumptions and to improve the design methods for future projects.

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