Diaphragm Walls and Challenging Anchoring for Historical Museum

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Technical and logistic challenges required innovative solutions to successfully create a safe, dry excavation within which three levels of the museum would be located. Excavation to depths of 59 ft (18 m) was required but the groundwater table was located at a depth of about 6.6 ft (2 m), resulting in a pressure differential of about 3,275 psi (157 kPa) acting on the bottom slab. Since the self-weight of the museum was insufficient, micropiles were used to anchor the bottom slab and the foundation slab against uplift/buoyancy.
Museum of the Second World War in Poland – Challenging Anchoring Against Uplift

One of the world’s largest historical museums is located in Gdańsk, in the Pomerania region in northern Poland. The Museum of the Second World War is situated in a symbolic architectural and historical space, very close to the iconic locations attacked in September 1939. The plot for the museum touches the Radunia Canal to the west, while its south side opens to the Motława River.

Construction of the museum was completed in 2017. It was one of the most interesting and demanding projects in Poland, and it has been widely discussed and bestowed with awards. The first stage, including the foundation works, was the most difficult part, not only because of structural challenges but also due to logistical and administrative burdens.

The architectural design of this unique building was developed by Studio Architektoniczne Kwadrat. Due to the scale (value about 110 million EUR or 122 million USD) and complexity of the project, the construction was divided in two stages. The installation and construction of the first stage was entrusted to the general contractor, Soletanche Polska.

The floor area of the building encompasses about 23,000 sq m (247,570 sq ft); however, the vision for the building was to hide most of it underground, with only a 40 m (131 ft) high leaning tower extending above the ground level. The exhibition spaces are located on three underground storeys, with the lowest one located about 14 m (46 ft) below the ground surface. This spatial division is symbolic: the past is represented in the underground levels and the future is expressed by the rising protrusion.
The building’s concept required creating an excavation up to 18 m (59 ft) in depth across the entire area of the 17,000 sq m (183,000 sq ft) plot. Due to the proximity of the Motława River, which resulted in a high groundwater level across the site, the foundation works and trench support work were complex and required the execution of the works being performed mostly underwater. In this situation, the first stage of the construction work included the “dry trench,” which enabled the commencement of the basic works related to the erection of the building. One of the biggest challenges of this first stage was to anchor the building against uplift, which is the main subject of this article.

Hydrogeological Conditions
In general, the geotechnical subsurface conditions at the site consist of a mineral-organic embankment layer that is 1.7 to 3.9 m (5.6 to 12.8 ft) in thickness, which is underlain by a peat and mud layer to a depth ranging from 7.4 to 10.7 m (24.3 to 35.1 ft). The peat and mud layer is underlain by a deeper substratum consisting of fine-to-medium, medium-compacted to compacted sands with a thickness of about 20 m (65.6 ft), which contain locally interbedded thin lenses of cohesive soils. The sandy formations are lined with sandy gravel in a compacted state. The groundwater level was found below the organic layers at a depth of about 1.8 to 3.2 m (5.9 to 10.5 ft) below the ground surface and was subject to fluctuations of about 0.6 m (2 ft).

Challenges and Technical Solution
The architectural assumptions and the existing geotechnical conditions generated numerous challenges for the geotechnical engineers. With excavation depths up to 18 m (59 ft) and a shallow groundwater table located at 2 m (6.6 ft) below the ground surface, the installation of a trench within the perimeter of the building plot made the dry trench stage exceptionally demanding. To create the excavation safely, the following process was utilized: anchored diaphragm walls were installed as the excavation support, then the earthworks were performed using silting methods as the trench was filled with water, then the concrete for the bottom slab was placed underwater, then sealing to complete a water cut off was performed, and, finally, the water within the excavation was pumped out. The slab for the building’s foundation and other structural components were constructed using traditional means in the dry.

With a head from the water column of 16 m (52.5 ft) (pressure of 157 kPa or 3,275 psf) acting on the bottom slab, the critical moment would be immediately after the water was pumped out from the trench. The self-weight of the openwork structure of the building proved insufficient to balance the buoyancy force. Therefore, it was necessary to install micropiles to anchor the bottom slab and the foundation slab against uplift.

The conditions existing at the site for the installation of the micropiles were extremely complex. Access to the front of the works was possible only from water, so the entire installation process had to be performed from floating vessels. As such, the challenges associated with supplying materials and providing support to the installation process also had to be considered and planned accordingly.
The distance through the water column (16 m or 52.5 ft) required that the micropiles be installed through an “empty passage” to the bottom of the proposed excavation (a depth of 17.33 to 18.33 m [56.9 to 60.1 ft]) with high precision to ensure proper location in the established grid. Moreover, the issue of anchoring the head of the micropile to the bottom slab, which would still be underwater, had to be solved. At the same time, it was necessary to ensure that the installation was efficient to be able to meet the tight time constraints as well as to ensure high quality and precision of the work performed.

The slab anchoring work was performed by Aarsleff, and required the installation of 914 micropiles in two phases that were located across a square grid with a center-to-center spacing of 4 m (13.1 m):

- Phase 1, temporary condition – for a period to not exceed 2 years from the time the water was pumped out of the trench to the completion of all construction works on the building, the tension load on a single micropile would be 2,300 kN (517 kip).
- Phase 2, permanent condition – after the completion of all construction works, the tension load would be reduced to 1,690 kN (380 kip) and the system would provide the required lifespan of 100 years.

The Ischebeck Titan self-drilling micropiles system was selected for use on this project. Based on the required individual load capacity, type 103/51 (4.06/2.01 in OD/ID) continuously threaded hollow bar micropiles with 220 mm (8.66 in) diameter drill bits were selected. The required length of each micropile was calculated to be 22 m (72.2 ft). Considering that the installation process had to be performed from atop the water surface, the length of empty passage through the 16 m (52.5 ft) height of the water column had to be added to the length needed to resist the uplift pressure. Thus, the working column of the micropile reached a length of nearly 40 m (131.2 ft).

**Suitability Load Test**

Before commencing the installation of the production micropiles, static load tests were performed on two sets of sacrificial micropiles that were installed from the ground level:

- Set 1 – 3 micropiles with a total length of 22 m (72.2 ft) measured from the working platform level
- Set 2 – 3 micropiles with a free length of 16 m (52.5 ft) to the target bottom of the excavation, while bond length was 22 m below (for a total length of 38 m [124.7 ft])

Therefore, the working conditions for the sacrificial micropiles were very similar to those for the structural micropiles. The reinforcement of the sacrificial micropiles was as a combination of 127/103 (5.00/4.05 in OD/ID) and 73/35 (2.87/1.38 in OD/ID) Titan hollow bars placed one inside the other. The design loads and the maximum load of 3,200 kN (719 kip) was achieved with the satisfactory performance of the work; therefore, the adopted micropile technology was approved for production.

**Installation Process**

Two contractors, Aarsleff and Soley were selected to perform the installation of the micropile works. To ensure high efficiency and precision, it was decided to perform the installation from floating platforms along with constant assistance and support from diving teams. Each contractor had its own floating platform equipped with a drilling rig, a material warehouse (for hollow bars, connectors, drill bits, cement, etc.), facilities for employees and a coordination center for the diving teams.

The involvement of the diving teams was crucial. In consultation with the team on the surface, the diving team was responsible for the activities for the micropile installation, inspection checks, measurements to control the quality of work, and providing information (e.g., continuity of grout or slurry flow or deviations) back to the team on the surface. Continuous cooperation and supervision of the divers was as important as the technical work itself. The surveillance center had a full overview of the underwater conditions, the divers’ work and the installation process, which, in severely limited underwater visibility, was critical.
A special procedure was developed for installation of the micropiles where a connector developed especially for this task (shell coupler) was used to maintain the tight schedule and required accuracy. The coupler is a type of a split connector that can tilt with a hinge, and it allowed the divers to unfasten the joint easily to release two sections of the micropile fastened to it. The shell coupler connected the working length and the upper portion of the micropile (within the water column) and was essential for the speed of the works that enabled an unusual installation process to be applied (significantly faster than using standard bayonet connectors).

The installation cycle used for the installation of the micropiles was as follows:

1. A column of hollow bars (the length of the empty passage) with a drill bit on the bottom was lowered through the water to the bottom slab.
2. After positioning the micropile column precisely by the divers, the drilling of the micropile was performed using the Titan self-drilling methodology (i.e., drilling without casing and with simultaneous injection of grout) with successive addition of sections of hollow bar, until the fixed length of the micropile in the ground was reached.
3. When the micropile was installed to the design level, the diver opened the shell coupler, which released the column of hollow bar within water column from the length of the working micropile installed in the ground.
4. Then, the diver attached another drill bit onto the disconnected section of hollow bar, which could then be used as the starting length of the next micropile without unnecessary dismantling and extraction to the surface.
5. For the micropile that was just installed, the divers attached the head of the micropile to the slab using a custom type connection (480 mm [18.9 in] diameter circular plate equipped with a threaded sleeve and handles) that also was developed specifically for this task, which allowed the divers to easily stabilize the washer plate in the appropriate position. A counter collar nut was tightened to the washer to complete the connection.

Thanks to these relatively simple technical solutions and excellent work organization, a very high production of 100 to 120 m (328 to 394 ft) of micropiles was achieved per day per work team within these unusual conditions. Nearly 22,000 m (72,178 ft) of micropiles were installed from January to early April 2014 (14 weeks), which is even more impressive considering that the peak of the work was performed during the difficult winter period. In addition, the accuracy of the installed micropiles (i.e., deviations did not exceed 20 cm or 7.9 in) was very good and easily achieved the required criteria.

Acceptance of Underwater Tests

The final verification of the quality of the works was acceptance load testing of the micropiles, which also was not a routine action. Because of the unusual access conditions, the depth of micropile heads and value of test load, underwater acceptance tests (a first in Poland) on three micropiles were performed. Along with the support of all the companies already involved, the technical capabilities and experience of Piletest facilitated the successful testing.

A supporting structure for the hydraulic jack was developed using a standard steel frame based on four supporting micropiles positioned around the micropile to be tested. Individual parts of the structure were lowered to the bottom and then assembled and levelled by the divers. A through-hole hydraulic jack and a set of strain gauges were used for the test. The tested micropile was
extended to above the water surface using a string of hollow bars so an optical measuring point could be mounted where the results from digital sensors were correlated with precise geodesy.

The task of assembling the equipment was a challenge for the divers. The work was carried out in limited visibility, and the required precision of the assembly was key for the success of the entire task — any imperfections could result in damage to the structure, equipment or micropiles. Thus, before the load testing program commenced, the diving team was trained. The whole procedure, including assembling and positioning the frame and measurement equipment, was firstly practiced at the ground level. Then each of the components (i.e., beams, displacement transducers, jack, etc.) were lowered and the testing structure was assembled and positioned underwater with use of special templates to assist the divers.

The actual test procedures, other than being underwater, did not differ from typical Polish standard testing procedures performed on the surface. Each of the installed micropiles achieved more than the required test load of 2,300 kN (517 kip) with associated displacements stabilizing in 30 to 40 min that did not exceed 25 mm (1 in).

**Bottom and Foundation Slab**

Successfully completed test loads paved the way for the last portion of this stage of work — forming the bottom slab. Underwater concreting for the bottom slab with an area of 14,300 sq m (153,924 sq ft) was one of the largest concreting works of this type performed in the world. It was designed and executed by Soletanche Polska. About 25,000 cu m (32,700 cu yd) of embedded concrete “one approach” elements built using Doboer technology was not only record-breaking but also made the bottom slab implementation a very logistically complicated operation.

After the concrete achieved the appropriate strength, water was pumped out of the interior of the excavation. After the surface of the bottom slab was cleaned, the micropiles were sealed, insulation was installed and the extensions for the micropiles were tightened to the assembly of the second heads (to join with the foundation slab). Then, the reinforcement work began, and subsequent stages of the construction work proceeded in a conventional manner.

**Summary**

The scale of the task and its complexity were exceptional, and the pressure of the tight schedule intensified the level of difficulty. There was no room for any material, technological or executive shortcomings, and the success or failure was determined by the details. The project required an individual approach and the use of unique technical solutions. The Titan micropile, supported by expert know-how, proved its effectiveness and allowed the project to succeed. The success clearly demonstrates the importance of commitment and cooperation of all participants in the process: technology suppliers, subcontractors, the general contractor and the supervisory authorities.

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