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Challenges & Solutions in Uplift Anchor and Uplift Pile Testing under Complex Geotechnical Conditions: Insights from Water-Filled Excavation Pits

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ABSTRACT: This paper aims to explain the challenges of executing and testing uplift anchors and uplift piles in complex conditions, such as in water-filled excavation pits or in the presence of highly variable geotechnical conditions and in the presence of esker materials. Soil consisting of glacially deposited sands, gravels and occasionally silty materials presents unique geotechnical uncertainties due to its heterogeneity, permeability and variability in mechanical properties. These factors influence the installation process and testing outcomes. During execution, grout loss at the borehole base due to poor rock quality and undetected voids was encountered. Corrective measures were required, such as removing failed anchors, re-drilling with cased drilling, increasing grout volumes and bond lengths, and installing significantly longer anchors. While these adjustments ensured successful testing, they also highlighted the unpredictability of grout behavior in challenging ground conditions. Testing from barges and water surfaces required additional engineering, setup, and precautions, as well as structural calculations to restrain pile head movement and increase buckling capacity under test loads. This was achieved using slings and chains, despite the difficulty posed by site constraints and simultaneous rig activities. Technical issues were further compounded by operational challenges such as long waiting times for cranes, frequent bridge repositioning and difficulties in placing and removing testing sleeves due to debris and water at the base of the pits. Despite these challenges, the project successfully demonstrated the ability to adapt and overcome unforeseen complications through innovative problem-solving and iterative testing processes. Enhanced installation techniques and refined testing protocols were implemented as corrective actions, ultimately ensuring anchor reliability. These findings offer valuable insights for future projects in waterlogged environments with complex geotechnical conditions and limited workspaces.

KEYWORDS: Anchor testing, testing in water filled pits.

1 INTRODUCTION

This vital waterway, which connects an inland lake to the Baltic Sea in Sweden, has served as a major shipping route since the early 20th century. Originally constructed in 1924, it featured the region's largest commercial lock at the time. After decades of operation, a comprehensive upgrade was launched to enhance safety and increase traffic capacity. The modernization plan included a new movable bridge, updated lock gates and increased dimensions to accommodate larger vessels.

Construction began in 2016 but was temporarily halted. Efforts resumed in 2021 with a renewed search for contractors to complete the project.

The execution and testing of uplift anchors and uplift piles presented significant challenges during construction due to the complex conditions, including water-filled excavation pits and the variable geotechnical properties of the esker materials. The heterogeneous, permeable glacial deposits, comprising sands, gravels and silty layers, introduced uncertainties in the mechanical behavior that affected the outcomes of the installation and testing. Grout loss due to poor rock quality and undetected voids necessitated remedial measures, including cased re-drilling, increased grout volumes and bond lengths, and the installation of longer anchors. Testing from barges and water surfaces required additional engineering to restrain pile head movement and enhance buckling capacity, which was achieved despite site constraints.

This paper provides an overview of the anchor and uplift pile testing that was carried out as part of a major construction project. It documents the testing procedures, challenges and outcomes across multiple excavation pits, and highlights the engineering solutions and adaptations that were implemented to ensure structural integrity and safety.

2 SOIL INFORMATION

The lock is situated within a river delta consisting predominantly of gravel, sand and cobbles with single graded particles in size up to 100–150 mm and large voids/cavities (locally referred to as 'cat-heads'). This material extends across almost the entire site, down to bedrock. Subsurface investigations indicate highly variable storage density, both laterally and with depth, which is characteristic of ridge deposits. Despite an observed increase in probing resistance with depth, the soils are generally assessed as very loose at considerable depths. Additionally, the rock was found to be 10 m deeper than indicated by the soil investigations. In some areas of the project, the rock quality was poor, causing some temporary anchors to fail. Cross sections prepared from the investigation illustrate the variability of subsurface conditions at different depths, as shown in Figure 1 below.

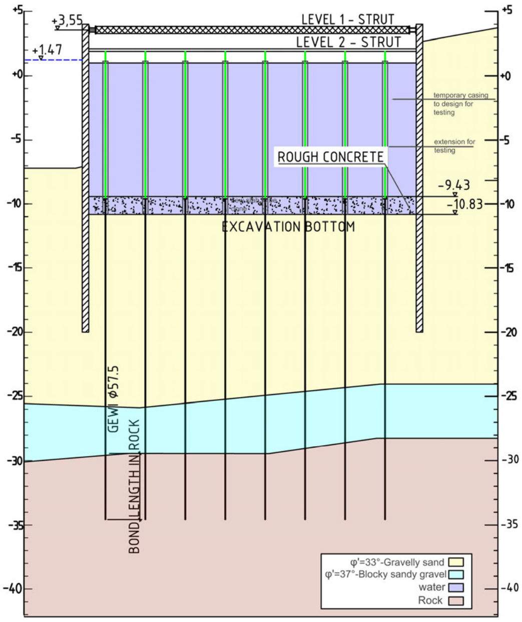

Figure 1. Cross section with soil profile.

3 ANCHOR AND UPLIFT PILE TESTING

Anchor testing has been performed for uplift piles, anchors inside piles and excavation support anchors within the scope of the project. A separate section detailing the testing procedures and analysis specific to each type of product will be provided. These detailed sections will serve as a reference for future assessments and maintenance activities.

3.1 *Testing of uplift piles*

Before explaining the procedure and testing, it is important to clarify the distinction in definition and intended use between uplift piles and uplift anchors. In this document, uplift piles are high-tensile alloy steel GEWI bars manufactured similarly to anchors, but without a lock-off load, whereas uplift anchors are designed with one.

Drilling the uplift piles was as challenging as testing them. Initially, the uplift piles were designed as soil anchors, but due to the poor soil structure and missing grain sizes, there was an extremely high need for grout to fill the borehole. Ultimately, it was decided to use rock anchors, which still required a high amount of grout, but all the performed tests showed positive results. All work relating to the execution and testing of uplift piles/anchors was carried out from a floating barge.

To test the uplift piles/anchors for the sealing slab, we designed and fabricated a special pile structure called a 'testing sleeve' (see Figure 2). Keller was responsible for the structural design of all parts of the sleeve; for example, even the steel plate below the anchor jack was checked using FEM to ensure that it would not be overloaded (Figure 3). This sleeve was used in water-filled excavation pits, as these pits already had a slab constructed prior to Keller's involvement. The main problem with using the testing sleeve was the debris that had accumulated on top of the existing 2–3 m thick concrete slab. It took many hours and a great deal of effort to position the sleeve in order to begin tested. Figure 4 shows the procedure for placing the testing sleeve in the water around the anchor/GEWI bar and the testing procedure.

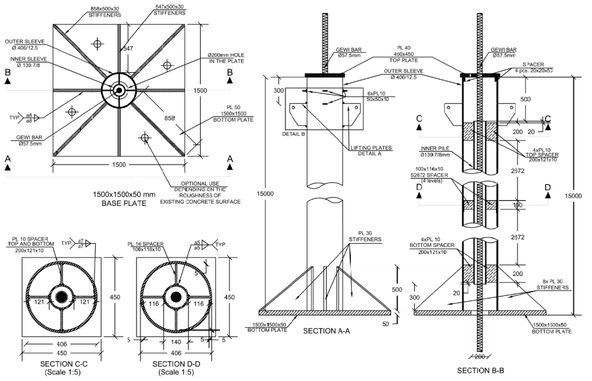

Figure 2. Design drawing of testing sleeve.

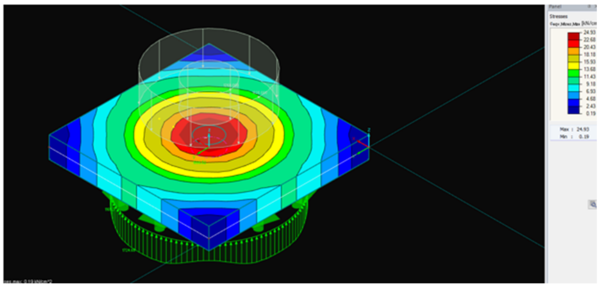

Figure 3. Example for FEM calculation on structural elements.

The temporary reaction assembly (base plate, sleeve, stiffeners and jack interface) is designed to safely apply and measure the prescribed proof load to bar anchors/GEWI during acceptance/performance tests, in accordance with SS-EN ISO 22477-5:2018 (Method 1) and the project specifications. Given water-filled pits and access constraints, the adopted system: centers the jack and maintains tendon alignment; distributes jack reactions through a stiffened base plate; allows clearance for GEWI couplers and jack installation.

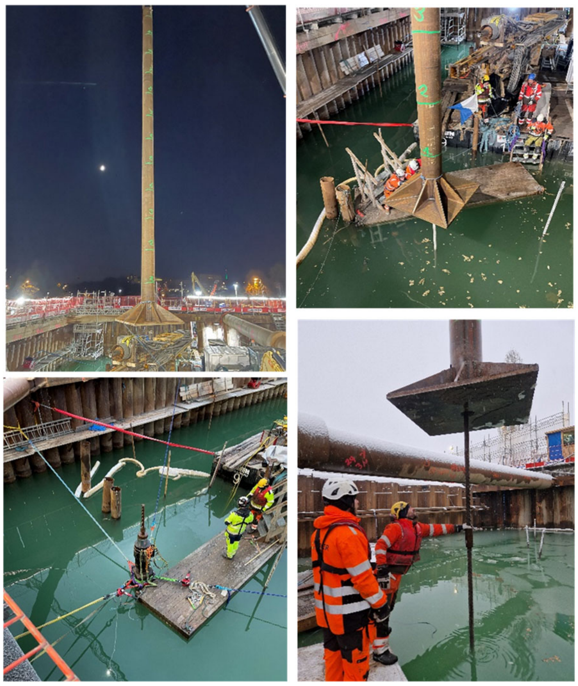

Figure 4. Photos from testing of uplift piles with testing sleeve.

Structural checks were also carried out, including a buckling assessment. This was because the testing sleeve had a free length in the water of up to 15 m and the buckling criteria were not met in the calculations. To provide lateral restraint and prevent instability at this point, therefore, the top of the sleeve was secured with chains to the retaining wall system (see Figure 5).

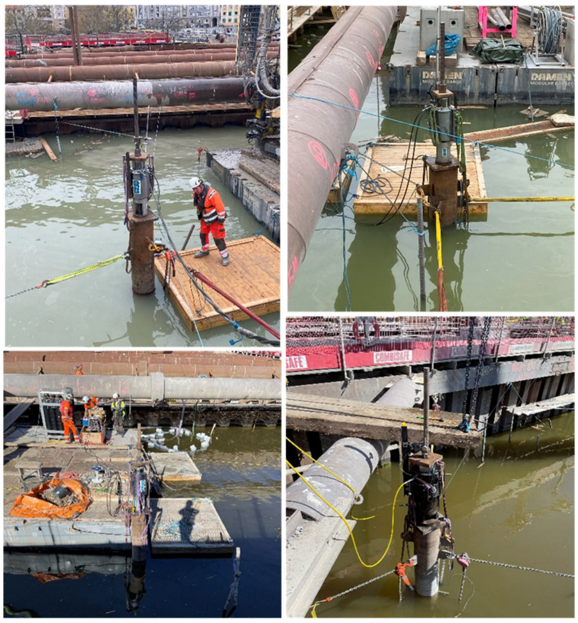

Figure 5. Chains securing the top of the testing sleeve to the retaining wall to provide lateral restraint and prevent buckling.

The previously described method was not applicable to all excavation pits. Therefore, a new method was developed for one pit, involving the use of a temporary bridge as a reaction structure (see Figure 6) for testing uplift piles up to a force of 1,382 kN. To use this bridge, back calculations were required to check the bearing capacity of the retaining walls, as well as a structural check of the bridge itself.

Figure 6. Testing uplift piles against a temporary bridge.

In order to carry out the uplift pile tests from the top of the bridge, holes had to be cut in the bridge surface. As the bridge owner initially refused to allow this, Keller prepared a backup solution to test from a suspended construction (see Figure 7).

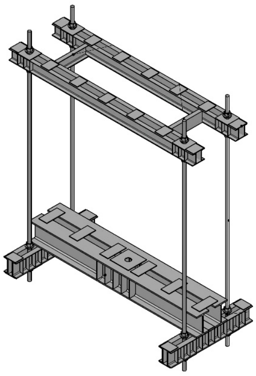

Figure 7. Suspended set up for testing.

3.2 *Testing of anchors*

In 2023, the permanent anchors in the secant pile wall were initially tested up to 600 kN and then locked at 350 kN. However, due to issues with the structural capacity of the existing load-bearing elements, a design for a temporary support structure was required in order to test the anchor to the final test load, which can be seen in Figure 8. In the second round of testing, which occurred in June 2024, tests were performed with a test load of 1446 kN, locking the anchor off at the same load as previously.

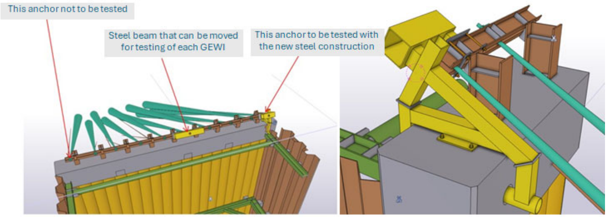

Figure 8. Temporary support structure for testing.

Two procedures were used for anchors inside piles, based on the test load. GEWI Ø35 mm anchors with a test load of 560 kN were tested without slings or chains. Eight of the anchors did not meet the required criteria during the initial test. Keller attempted post-grouting using pre-mounted hoses and monitored water levels to assess grout retention. Although the water levels stabilized, indicating a sealed pile bottom, retesting after seven days did not fulfil the given criteria.

Subsequently, the temporary GEWIs were removed – some more easily than others, which required the use of hydraulic jacks. Examination revealed a lack of grout around the bottom 1.5–1.8 m of the anchors, indicating grout loss into the borehole base. Keller re-drilled and reinstalled longer GEWIs using cased drilling, also increasing the installed grout volumes. During re-drilling, cement was found extending up to 5 m into the rock layer below the original anchor base. New anchors, up to 13 m longer, were successfully tested after the grout had cured for a minimum of seven days.

Several anomalies were linked to unpredictable rock behavior, including grout disappearance, the need for longer piles due to poor rock quality, failed 'stoppslagning' -the Swedish method for dynamic pile testing and proofing, e.g. to ensure that steel piles are installed into competent rock- (Pålkommissionen, 2016), and sinking piles during PDA testing.

To test the permanent anchors inside the piles, the buckling capacity of the piles was checked under test loading, since the piles were being used as a reaction system. Structural calculations showed that restraining the pile head movement using slings and chains was necessary to increase the buckling capacity on site. To mitigate the risk of buckling of the steel pile during testing of the Ø63.5 mm GEWI with a test load of 1.45 MN, the pile top was fixed in the lateral direction using chain blocks (see Figure 9).

Figure 9. Testing of anchors in piles.

Although it was a good theoretical solution, it was very difficult to implement on site, partially due to rig and machine movements and space was limited everywhere in the pit. Figure 10 shows what the chains look like in plan view.

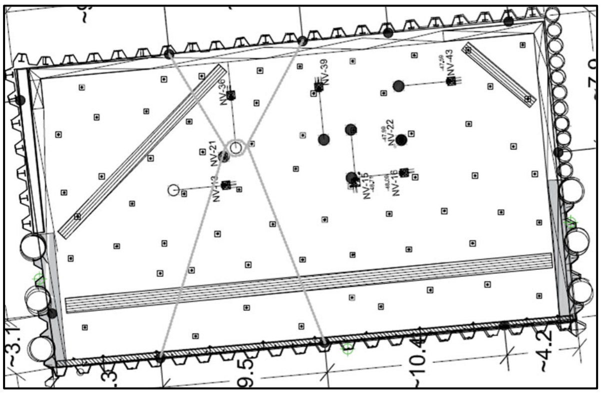

Figure 10. Plan view of one of the excavation pits showing.

In addition to the anchors inside the steel piles, permanent anchors have been installed in one of the excavation pits in order to actively pretension an underwater concrete slab. Testing was performed using a temporary bridge construction in combination with a testing beam designed for a test load of up to 5 MN (see Figure 11). Once testing was complete, divers removed the extension piece of the anchor to allow access for installing a permanent anchor head construction underwater. Once the underwater slab had been cast and cured, the Keller team and the dive team proceeded to tension and lock the anchors. Challenges included poor underwater visibility and the absence of a helmet-mounted camera, meaning the diver had to verbally describe to the test engineer how the domed nut was seated within the concave anchor plate (see Figure 12).

Figure 11. Testing permanent anchors against a temporary bridge.

Another challenge for the diver was to identify the specific anchor underwater and install all the elements according to the 'dry training' they underwent before entering the water.

Figure 12. Diver installing the anchor jack.

4 CHALLENGES DURING TESTING

A common challenge in all areas of construction was to develop a safe method of testing uplift piles and anchors, which required various structural checks and customized support structures.

Working from barges in the water and surrounded by water during testing usually required an independent measurement of the GEWI elongation from "land". Therefore, surveyor support was used to provide reference measurements from stable positions.

Ship traffic and lock openings significantly influenced anchor testing on a drilled steel pile retaining wall downstream. The waves caused by water flow or passing ships were clearly visible on the dial gauges and the pressure holding device on the hydraulic unit. Consequently, some tests had to be repeated because the initial results were distorted during the first testing process.

Due to the variety of five different GEWI diameters in combination with different anchor head constructions (hexagonal nuts vs. doomed nuts), anchor length and test force, it was always a logistical challenge to have the best-suited jack with valid calibration on the spot – see Table 1.

The weather conditions were not always favorable for the testing team. For example, the hydraulic unit had to be heated during extreme winter conditions of -19 °C, which otherwise caused problems with the viscosity of the hydraulic oil.

As a general rule, GEWI bars in piles were tested twice in 2% of all tests to verify repeatability, as the initial load-deformation curves fell below the lower boundary limit. These GEWI bars do not function as conventional ground anchors because no long-term tension load is applied to lock them off. A higher *Lapparent* value was observed for these GEWI bars than the maximum limit specified in Annex D of SS-EN ISO 22477-5:2018, but this does not necessarily indicate a performance issue in the same way as it would for a pre-tensioned ground anchor. Instead, it primarily reflects the stiffness of the bar, the embedment conditions and the specifics of the test setup. To ensure reliable results, repeatability testing was conducted within ±5%, as specified in the anchor testing standard SS-EN ISO 22477-5:2018. Additional consistency checks were performed to verify measurement repeatability, validate the equipment and setup, and assess short-term deformation and creep behavior under the applied test load.

Table 1. Summary of anchor tests.

Type of use	Diameter (mm)	Test Load (kN)	Number of tests
GEWI inside pile	35, 43, 50, 57.5, 63.5	560~1900	~400
Uplift anchor	43	750	
Uplift pile	57.5	1125~1415	
Excavation support anchors	43, 50, 57.5, 63.5	600~1500	

5 CONCLUSIONS

Eight different anchor testing and stressing methods were applied and partially developed, successfully solving this part of the technical challenges on the lock project. This significantly contributed to ensuring the buildability of the entire project and keeping to the timeline.

This project demonstrates that close, fair and open cooperation between the main contractor, the geotechnical construction company and the designers yields good technical, commercial and time-efficient results for all parties involved. The success of the project was especially due to the combination of geotechnical design and execution competency available on site.

6 ACKNOWLEDGEMENTS

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7 REFERENCES

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