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PNEUMATIC SINKING 2.0, OR 'HOW DEEP CAN YOU SINK (FROM A GEOTECHNICAL PERSPECTIVE)'

Old and new Kattwyk Bridge

The port city of Hamburg is built in the delta of the Elbe River. There are several bridges to reach the city regarding which the existing Kattwyk Bridge is located on the central railway route between the eastern and western port area. The bridge also has a local but important traffic function including for the connection with the A7.

The bridge was built in 1973 and bridges the southern section of the Elbe. It is one of the largest vertical lift bridges in the world. The high lifting towers create a characteristic architectural focal point. The combination of railway and road, however, represents a problem these days due to the relatively narrow bridge. If a train needs to pass the bridge, road users cannot use the bridge since the railway runs over the road lanes. This leads to frequent traffic jams.

A new bridge was therefore urgently needed. The decision was taken to build an extra bridge with the same shape that is especially intended for trains.
The tender was won by the construction combination Max Bögl-H.C. Hagemann-Heijmans.

The new bridge that has a total length of 287 m is being built approximately 60 m to the north of the existing bridge. The bridge will be lifted more than 50 m above the water when it is open, which is the same height as with the existing bridge. There is a distance of 131 m between the piers and they are approximately 75 m from the river bank. The decision has been taken to build a microtunnel between the two piers at a depth of approximately 24.5 m for the cabling to assure a symmetrical movement during the lifting movements of the bridge.

The piers themselves have an area of 29 x 14 m2 and a foundation level at 30.0 m below standard zero ('Normalnull').

Geotechnical conditions

The soil where the piers are located has been surveyed by means of borings and CPT's. Performing CPT's, however, was difficult. The reason for this may be a very hard soil or the presence of stones in the top stratum. The soil survey has shown that the soil can be characterised as follows:

The soil survey has shown that the soil structure under both the piers shows large differences in this basin area. The location at the south westerly pier is, for example, characterised by a melt water sand layer that is approximately 8 m thick, gritty in nature with possibly larger stones and underneath strongly layered clay and silt formation. At the

Figure 1 – New Kattwyk Bridge sinking location, Hamburg.

SUMMARY

The New Kattwyk Bridge in Hamburg is currently being realised by the Hamburg Port Authority (HPA). A special construction method was chosen for the realisation of the river piers. The pneumatic sinking technique, among other specialties, was used in relation to this. Pneumatic sinking means working under an overpressure with all the safety measures that this entails. It also means that working hours are seriously limited when sinking up to a water depth of 32 m. Volker Staal en Funderingen (VSF), the subcontractor for sinking the river piers of the New Kattwyk Bridge, has therefore mechanised the sinking process innovatively. The soil under the caissons is excavated in a remotely controlled manner and disposed of while deploying occasionally.

This article discusses the implementation concept for the river piers, the development of sinking in a remotely controlled manner and the expected and unexpected challenges that must be resolved during implementation.

Table 1 Description of the soil structure at the pier locations

Stratum	*SW pier [m below standard zero]*	*NE pier [m below standard zero]*	*Soil description*
River bed	-9.8 +/- 0.7	-12.1 +/- 0.5	
Backfill material	N/A	-13.9 +/- 0.3	Sand with mussel shells and with varying peat, silt and rubble content. H2S was clearly released from the samples.
River sand	-11.2 +/- 0.6	-14.7 +/- 0.6	Varying silt, peat, wood, shells and sludge content.
Melt water sand	-19.3 +/- 0.9	N/A	Possibly strong gravel and stone content with silt layers. Predominantly compacted.
Basin silt	-30.9 +/- 2.2	-19.1 +/- 0.6	Very different in thickness. Built up from very thin clay and silt layers with a regular sand content. Contains much fine organic material (approx. 10%). Predominantly rigid behaviour and very cohesive.
Basin sand	-37.3 +/- 0.1	-36.5 +/- 0.5	Fine sand with a varying silt and clay content. Also strata with lignite. Predominantly qc up to 25 MPa.

Figure 2 – New Kattwyk Bridge impression.

Figure 3 – Building the concrete pier suspended from bars.

north easterly pier, the sand stratum formed by glaciers is not present, but the clay/silt formation is found at a higher level with a relatively small thickness and underneath a thick older sand layer.

Pier construction method

Constructing at a great depth in the middle of a busy industrial area sets quite some requirements and preconditions in relation to the design and implementation. The average water depth amounts to approx. 11 m above the river. This increases by more than 2 m during a normal high tide, but this can even increase to nearly 6.5 m when there is a heavy storm or spring tide. Therefore, something to be taken very seriously. The client therefore decided to use a very special construction method. Figure 3 provides insight into the construction method. A cofferdam using combined sheet pile walls was realised for each pier in the river but with the one side still open. On top of this, a steel structure frame was installed with a height higher than 10 m above standard zero.

The concrete floor area of the bottom plate including the edges of the cuts of the pier was made on a pontoon near the quay at that time and subsequently sailed into the cofferdam during high tide (1). The bottom plate was lifted in by means of 24 heavy Gewi bars connected on to the steel structure and the pontoon could, in this way, again be sailed out of the cofferdam during low tide. Once the cofferdam had been fully closed, the construction of the pier could really get started (2). The concrete pier was constructed suspended from the Gewi rods in sections of approximately 5 m alternating and it was jacked downwards (3+4). After the structure was placed on the cleaned up soil, the equipment for sinking could be built and the suspension could be removed in a controlled manner (5). The sketches 5-7 only show the installation of water cannons and a pump as conventionally used in caisson sinking. The characteristic access airlocks and air pressure system have been left out in the sketches. A spectacular construction method on the water and the pneumatic sinking had not even started yet!

Sinking method

Sinking caissons and certainly pneumatically is not a very well-known technique in the world of foundations. This technique, however, already exists 200 years and, in the Netherlands, since the end of the 19th century. The word 'pneumatic' refers to the application of increased air pressure in the working chamber under a caisson to thus create a dry working space making the controlled removal of soil possible. Until halfway through the last century, serious accidents occurred regularly in relation to workers that were tasked with the job. This is why the term 'caisson disease' (decompression sickness) was used without people knowing the cause, how to prevent it or how to treat it. Legal precaution measures, however, were already taken in the Netherlands at the start of the 20th century. This was known as the Caisson Decision that was part of the Mining Act. Knowledge and insight only really changed with the development of diving after World War II, in particular in the navy. And, in the Netherlands, also due to the professional deployment of large hydraulic construction projects such as the well-known Delta Works (in Dutch: Deltawerken) in the 1970s and 1980s for dyke safety along the North Sea. Nowadays, specialised and certified diving doctors are trained. Decompression and treatment tables have been developed with specific procedures for caisson workers. VSF has proven with thousands of 'dry diving' instances at many projects in the Netherlands that caisson work can be performed safely.

However, working under overpressure is far from ideal, even though the risks to health are minimal. The work is labour intensive, in particular in cohesive soil and at a greater depth. A greater depth, after all, means a higher water pressure and therefore a higher air pressure to keep the working chamber dry. This results in seriously restricted working hours.

Sinking 2.0

Up to now, sinking in Europe took place by using caisson workers who worked in the working chamber under the caisson. After atmospheric locking-in up to the set overpressure, the soil is usually jetted in a targeted manner to remove it using water cannons. The mixture of water and soil is, subsequently, taken outside the caisson in containers or a sludge depot. Sometimes, small excavators are used, in particular in corosic soil of hard strala. The soil is taken outside, in this case, using buckets lifted each time through a material airlock.

Workers climb up to the people airlock after every shift. Decompression takes place, in steps, in a controlled manner until obtaining atmospheric pressure and by using respiratory equipment with pure oxygen. Outsiders often believe that this is dangerous and dirty work, but those immediately involved believe that they are the greatest project experiences that you can have. Playing with sand and water is fun at any age and, as a geotechnical engineer, it is unique to really see and feel the soil to a great depth!

As already said, however, working under an overpressure with teams is most definitely not ideal. It is labour intensive and therefore less competitive than building in a building pit. The communication with the caisson workers is also difficult because of the sealed chamber and this is at the expense of efficiency. A development to obtain a new sinking version was therefore required. With projects in its portfolio such as the New Kattwyk Bridge and also the lock heads of the New IJmuiden Sea Lock, central to the port of Amsterdam Volker Staal en Funderingen was given the opportunity to give its market leader role in this technique an extra boost. The objective is to remotely control the sinking so that caisson workers only have to work under an overpressure with regard to the installation and maintenance. The entire process of releasing the soil, transporting it in the working chamber and removing the soil from the working chamber is considered in many variants during the development process but also the drive: hydraulically, electrically or pneumatically for the movements, and cameras and sensors for monitoring. Close collaboration took place with regard to this, an engineering firm and machine builder. A significant pitfall that is known from much practical experience is to want to build a machine that can do nearly everything and is suitable everywhere: What is commonly referred to as expecting the impossible. The trick was therefore to design and build a machine that is suitable for approximately 80% of the contemplated market area that is

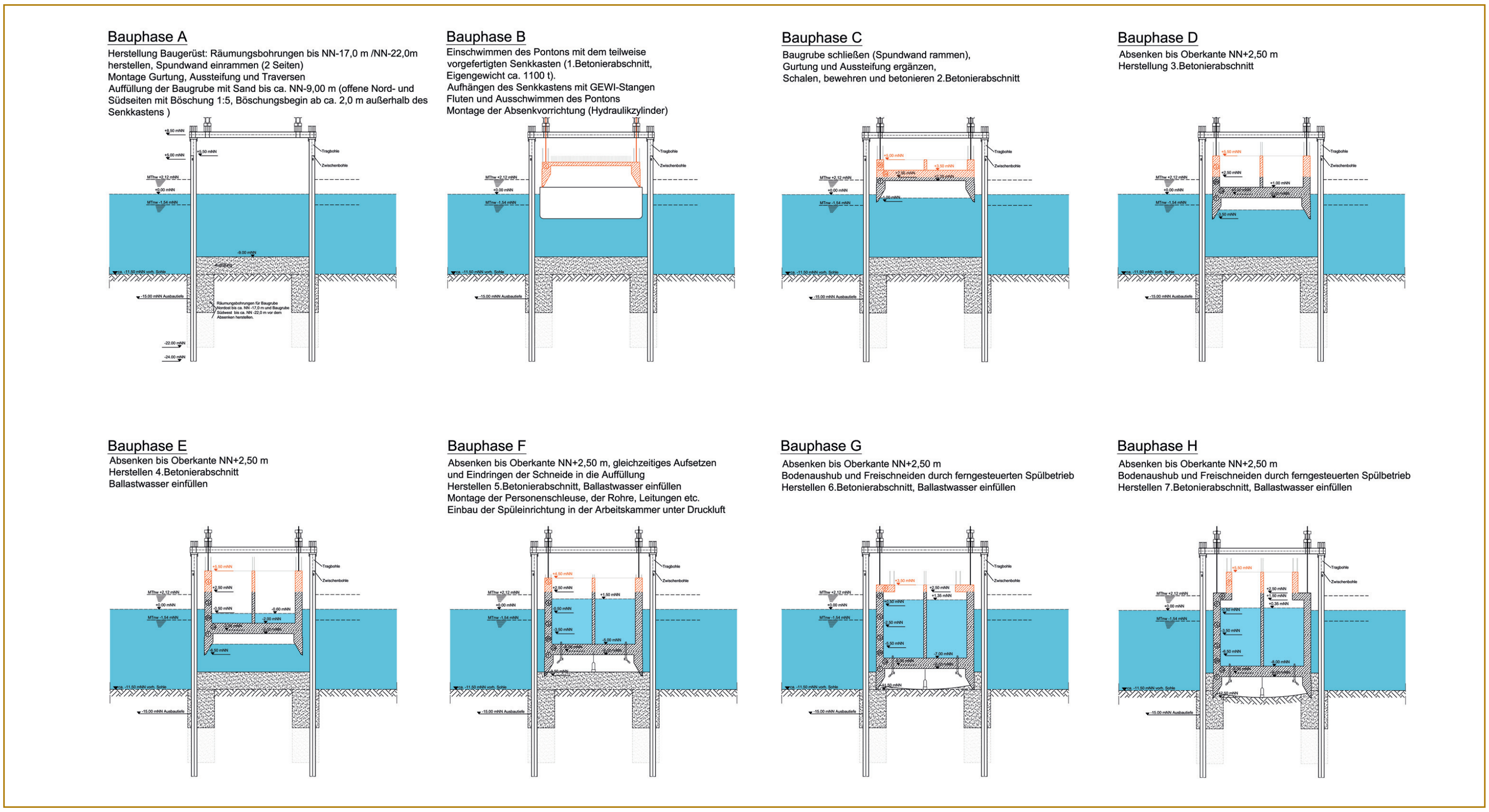

Figure 4 – Phasing of the bridge pier realisation.

Figure 5 – Pier sinking situation.

new with regard to its type, but that is robust and reliable.

In East Asia, they already started to mechanise sinking over 20 years ago. They developed excavators that are suspended from rail structures there. Remotely controlled, soil is deposited in buckets that are lifted up from the working chamber through a material airlock, emptied and again locked in. This system works in basically any soil type and is applied on a large scale by Japanese companies in particular. It does, however, have a considerable disadvantage. Productivity is very low. The aspect that needed to be improved was productivity. VSF decided to check what already exists in the field of technology related to earthmoving and dredging soil conditions related to delta regions. This finally led to a concept with cutting head pumps installed on an arm that can be moved in three directions. Turning arms have been developed that can be extended up to 14 m! The reason for this is that this allows the direct dredging of soil material with a reach that is the largest possible. Outside of this reach, there is a combination with powerful remotely controllable jets that are installed on to the ceiling of the

Figure 6 – Excavation arm in the working chamber.

working chamber. Dredging pumps could be used that were already available on the market. The most important criteria when making this choice was limiting the weight, having sufficient pumping capacity for sufficient flow speed in the long pipes and an outlet opening that was the largest possible for pumping gravel.

In addition to sensors in the hydraulic drive of the different motors and cables, investments were also made in cameras that are suitable for the special conditions that can occur in the working chamber. It is not just the increased air pressure that is a factor that must be considered, but mist will already be created when small pressure reductions occur. Droplets rain down with soil when jetting and there is a risk that the lighting may disrupt instead of support visibility due to shimmer or glare. In short: compressive strength, cleaning systems and high light sensitivity formed the key conditions when developing the cameras in combination with a good light plan.

Extensive testing is, of course, an integral part of such a development. The design process was developed based on extensive reviews by different experts. A testing set-up was made to develop the combination of jets, camera and lighting. When the first machine was delivered, a test location was built to install the equipment airlock and build the arm structure through this. This was done to train employees in operating but also in installing and disassembling in a sealed working chamber.

Figure 7 – Remotely controlled excavation.

Figure 8 – Stones and rocks - a mountain of obstacles.

Project experiences

And then it really had to happen! The piers had already been installed on the river bed of the Elbe; therefore at approx. 11 m below standard zero. The building of the air pressure equipment in the North-East pier started in January 2018. Next, the equipment airlock could be installed. The equipment was introduced into the working chamber in sections with a maximum length of 2 metres and installed. A temporary equipment airlock was installed on the floor for this.

This ensured that sinking could be started in phases of at most 5 m. After every sinking phase, the pier could again be built up further after which another sinking phase followed. See figure 3, phases 6 and 7. In total, every pier was sunk in this way in five steps up to the final depth of more than 30 m below standard zero. All equipment was removed in the working chamber at this depth. Next, the chamber was filled with concrete as ballast to prevent uplift during the following construction phase. There were, naturally, a few start-up issues and teething problems, but these remained within what can be reasonably expected. The presence of obstacles and rubble in the top soil layer also led to damage to pumps occasionally. The real delay, however, was caused by the previously mentioned melt water sand layer under the South-West pier. The addition of sand to the name of this layer turned out to be fairly misleading. Significant resistance had already been noticed when the combined sheet pile walls were installed and many stones and rocks came up during pre-drilling. It was reported that an old creeck had been found filled with stones that runs obliquely through the location with a width of approx. 6 m. Mainly sand and gravel but with some stones and rocks. Some delay did then have to be taken into account although pumps with a clearance of 100 mm were specifically selected. 'Some stones and rocks' turned out to be an understatement because, in practice, it was a lot tougher.

There was a stratum over virtually the entire area that was nearly 7 m thick consisting of mainly stones and rocks that had consolidated to a significant degree. Jetting the soil loose was not really possible, nor was pumping. In total, nearly 750 tonnes of rock were removed from the caisson by the caisson workers! A very heavy job but they did it! The NE and SW piers were installed on 22-8-2018 and 1-10-2018, respectively, at the final depth. Well within the set tolerances.

To conclude

The sinking of caissons is a fantastic foundation technique intended for structures that must be built at larger depths. Usually, construction takes place at ground level and therefore a deep cofferdam with the risks that this entails is not required. Techniques to realise deep cofferdams have evolved significantly during the past decades. Volker Staal en Funderingen has taken a large step forwards with the development of a remotely controlled sinking method to offer a fully-fledged alternative. A development that was only possible in collaboration with various experts, suppliers and customers.

Currently, the lock gate heads of the New IJmuiden sea lock are being realised. These concern caissons with mega dimensions. The outside head measuring 26 x 81 m2 is currently installed at a depth of 24.3 m. The inside head measuring 55 x 81 m2 will be the biggest caisson ever built and will be installed at 25.55 m depth in spring 2019. This will also be within unprecedented tolerances such as a torsion of 50 mm and tilting across and in the longitudinal direction of 0.3% but with a target value of <0.1%. That is our goal with sinking 2.0!