Kingpost Wall at Carlsberg, Denmark: Design, Construction, and Supervision
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ABSTRACT Over the next 10-15 years a new city district is being developed on the historical site of the former Carlsberg brewery in the heart of Copenhagen. Today, the site is part of the Danish cultural heritage where many of the architectural treasures of Copenhagen are located. When finished, the Carlsberg City Center will comprise of almost 600,000 m² of new floor space. To accommodate the increased transportation needs in the area, a new train station is being built on the existing train network. The foot of a slope is removed to make room for one of the tracks of the new station. To ensure the stability of the slope a retaining wall is needed. The top view of the stretch is shown in figure 1 and is approximately 100 m long. A cross section of the geometry is shown in figure 2.

1 INTRODUCTION

Over the next 10-15 years a new city district is being developed on the historical site of the former Carlsberg brewery in the heart of Copenhagen. The first buildings on the site were constructed in 1847, when the Carlsberg brewery was moved there. Throughout the 1900s the brewery expanded and constructed many buildings on the site, and until 2008 the majority of the beer production took place there (Carlsbergdanmark.dk, 2015). Today the site is part of the Danish cultural heritage where many of the architectural treasures of Copenhagen are located. When the comprehensive renovation and development is finished, the Carlsberg City Center will comprise of almost 600,000 m² of new floor space divided into private residences, retail and business premises as well as cultural, sporting, and educational venues. To accommodate the increased transportation needs in the area a new train station is being built on the existing train network (Carlsbergbyen.dk, 2015). One of the existing tracks has to be moved in order to make room for the station. Because the tracks are lower than the surrounding terrain on both sides, the foot of a slope alongside the track is removed to make room for the track. To ensure the stability of the slope a retaining wall is needed. The top view of the stretch is shown in figure 1 and is approximately 100 m long. A cross section of the geometry is shown in figure 2.

Geo, a Danish consultant agency with subsurface expertise, were hired to design a roughly 100 m long retaining structure. On paper it is a relatively simple task, but it proved to be very difficult due to several factors.
2 DESIGN

2.1 Accessibility and site investigations

The biggest challenge of the project is the location. On one side of the retaining wall is the busiest stretch of the entire rail network in Denmark with four tracks where all railway traffic in and out of Copenhagen towards west has to pass. On the other side of the retaining wall is a relatively steep slope and on top of that is a protected park. Furthermore, a bicycle track is planned to run alongside the retaining wall on top of the slope (see figure 2). This means that the accessibility is very limited, and the first time this proved to be a problem was in the initial design phase, when planning the site investigation. The price of three or four geotechnical boreholes would simply be too expensive and too time consuming for the client due to the accessibility. The only knowledge of the ground conditions we had in the initial design phase therefore derived from a large site investigation placed 25–50 m east of the retaining wall. Defining the design parameters based on boreholes located as far as a couple of hundred meters from the retaining wall would be associated with great risk. Luckily, due to another project nearby three boreholes became available for us. The locations of the boreholes are shown in figure 1. As seen, the locations of the boreholes are still far from optional regarding the retaining wall. However, the literature states that the railway, when constructed in the middle of the 1800s, was cut through the terrain (the original terrain is shown in figure 2; Frederiksen, 2002). This means, that we can be relatively certain that there is the same geology in the boreholes as on the location of the retaining wall. The three boreholes parallel to the retaining wall showed similar ground conditions as the big site investigation, so we could now establish the proper design parameters for the soil.
2.2 *Ground conditions and type of structure*

The soil in the location is generally clay till. The clay till stretches from the terrain on top of the slope all the way to the chalk well below the tracks. The undrained shear strength of the clay is increasing with depth and varies from 200 kPa to >750 kPa. This means that the clay till is extremely hard in some places and some might even characterize it as soft stone. The hardness of the soil means that the only solution is a king post wall for the retaining wall. The most efficient solution would usually be a sheet pile wall, but the ground conditions combined with the accessibility would not allow for the required size of machinery to be brought in. Tests were actually carried out, but it was impossible to bring the sheet piles more than a meter or two into the ground.

![Figure 3. Principle of construction a Kingpost wall. 1) Holes for the piles are drilled. 2) Piles (of steel profiles in this case) are placed in the holes and concrete is casted around the profiles. 3) Plates are placed between the piles.](image)

A king post wall (also known as a Berlin wall or soldier piles) consists of vertical piles equally spaced and driven or drilled into the ground. Above the excavation level, plates are placed between the piles. Due to the ground conditions it was decided to use steel profiles in drilled holes and cast concrete around the profile. Between the profiles above the excavation level, steel plates are welded between the steel profiles. This principle is shown in figure 3.

Because the retaining wall is right next to the railway the track closest to the construction needs to be shut down during the construction. The track could only be shut down during the night and combined with a fixed timeframe to where the new track must be in operation it is essential that the design is optimized to have as few piles as possible. The hard clay till and the accessibility means that there is a limit to how large the diameter of the holes can be due to the drilling machinery that could be brought in. This additionally affects how large the steel profiles can be. To be able to maximize the spacing between the steel profiles, high grade steel HE...M profiles is used.

It would seem obvious to anchor the wall to save time on the drilling of the piles and on the amount of materials used. Unfortunately this is not possible due to the protected park above the slope. The anchors would have to be relatively long which would cause them to go all the way under the protected park. When the park is protected so are the roots of the trees, and therefore anchors could not be used.

When a construction is changed or renovated, the new construction must fulfill the requirement of the present day standards and codes (Bane Danmark, 2010). Because the original slope next to the construction is unstable (when analyzed by calculation), the height of the retaining wall must therefore be chosen, so the slope can be levelled out and the total and local stability can be verified. This needs only be applied on the stretch where the track is being moved even though the slope continues a couple of hundred meters towards west. No modifications of the slope
are needed towards west because no physical change is made to the slope or track.

2.3 Bicycle track

Almost throughout the entire design phase we had very little knowledge of the bicycle track above the retaining wall. The only information was that it was founded on piles. The client was informed that the design we would propose could be drastically changed depending on the length of the piles and was well aware of this during the entire design phase. The client had tried to get detailed information about the bicycle track for us, but because it was a different contractor and a different design team, this was practically impossible. It was not until we had delivered the complete design that we got the right information about the length of the piles. Luckily for the client, the piles for the bicycle track extended two meters below the tip of the piles for the retaining wall, and therefore did not create any extra load; on the contrary, they are helping to ensure the total stability of the entire system.

3 CONSTRUCTION AND SUPERVISION

3.1 Special drill

The hard clay till caused problems in the first phase of the construction, as the contractor needed to bring in a special machine from Sweden, which is normally used to drill holes in bedrock, to drill the holes for the piles. The contractor did not have a machine in Denmark that could drill the holes fast enough. The machine that had been brought in had no problems drilling through the hard clay till, and the contractors were finished ahead of schedule.

3.2 Drain and sewers

The time gained on the drilling was quickly used on the excavation work for the drain and sewers in front of the wall. After the design was finished, the drain and sewers were moved from the four tracks to the front of the wall. We assessed that the position of the drain and sewers in the permanent situation would not be a problem, but the wall could not be proven sufficient for the temporary 1.5 – 2.0 m deep excavation required for the drain and sewers. We informed the client and the contractor that there would be great risk involved with the excavation, and that it would most likely result in large deformations in the permanent situation as well as during the excavation process. The client and the contractors were willing to take the risk as the position of the drain and sewers in front of the wall was the only solution. In order to limit the amount of damage in case of an accident during the excavation, the contractors were told to construct the drain and sewers in steps. This method of excavation combined with excavating in the very hard clay till proved to be much more time consuming than planned.

Figure 4. Cut off steel profiles.
3.3 Cut off profiles

It was not until the excavation for the drain and sewers began that we were hired to do the supervision. This meant that all of the piles were placed and almost all of the plates between the piles were placed as well. During one supervision, some cut off steel profiles were seen on one of the contractors’ railway wagons (see picture 4). This seemed peculiar as the contractor had previously stated that all the profiles were ordered in the required length so no adjustment on site was necessary. We acquired the logbook from the contractor indicating the level of the tip of all the piles. After a couple of months we finally received the information showing that the length of 11 piles had been shortened; three of which were cut off by as much as 1.5 m. The reason for this was not given. This means that a couple of the piles stand with a partial safety factor equal to one. By the time of writing this paper we still do not know if anything is being done to accommodate this shortage.

3.4 Remaining work

The retaining wall should have been completed around Easter 2015 when the new track should have been fully operational, but as of May 2015 the construction is still not finished. The piles and plates of the wall, drain, and sewers were finished so the track could be fully operational in time, but all the work on the backside of the wall still needs to be done. In figure 5, the construction is shown as of the beginning of April 2015.

4 CONCLUSION

This article has described some of the problems and challenges encountered in the design and construction of a kingpost wall. Although we have yet to see the finished structure, the most essential part of the structure was finished in a way that did not disturb the railway traffic on the busiest stretch in Denmark.

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REFERENCES


Figure 4. The Kingpost wall as of the beginning of April 2015. It can be seen, that the construction of the bicycle track is been constructed and the slope has yet to be leveled out.