Establishing a high risk construction pit in a hurry

L'établissement d'une excavation profonde à risque élevé en court temps

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ABSTRACT: In order to establish a cut & cover road tunnel in Copenhagen, a deep construction pit is established. The future tunnel will run below four railway lines and alongside a fifth, the latter being in poor condition. Since all five railway tracks are vital for the infrastructure in the region, it was not possible to close down all lines during the construction period simultaneously. In fact only two fixed and extremely short closures were allowed for in the construction schedule. This paper presents the thought processes and considerations of the parties involved during the design and planning phase and contains a description of the outcome, that is, the chosen solutions and structural elements.

RÉSUMÉ : Afin de construire un « cut & cover » tunnel routier à Copenhague, une excavation profonde est réalisée. Le futur tunnel est construit sous quatre lignes de chemin de fer et à côté d'une cinquième, cette dernière étant en mauvais état. Étant donné que les cinq voies ferrées sont vitales pour l'infrastructure de la région, il n'était pas possible de fermer toutes les lignes au cours de la période de construction en même temps. En fait, seulement deux fermetures fixes et extrêmement courtes ont été accordées par les autorités. L´article présente les considérations faites par les acteurs concernées lors de la conception et la phase de planification du projet et une description des résultats et les solutions choisies.

KEYWORDS: Construction pit, Temporary retaining structures

1 INTRODUCTION

In Copenhagen a cut & cover tunnel is being established as a part of the new road Nordhavnsvej connecting an existing motorway with the city center of Copenhagen. The construction period is 2011-2015.

The tunnel is a traditional concrete twin tube box tunnel with two road lanes in each tube, build bottom up in a dry construction pit. The length of the tunnel is about 650m.

The alignment of the future tunnel runs below four railway lines at ground level, along a fifth railway line in an old fragile tunnel, below a busy main road and into a narrow path between existing buildings. Figure 1 shows the horizontal alignment and some of the key structures

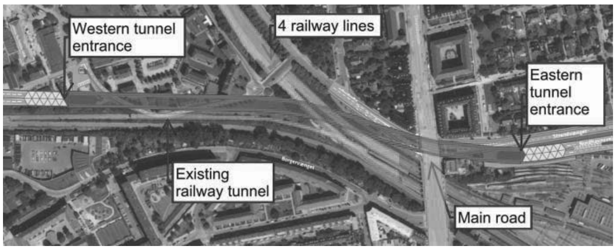

Figure 1. Horizontal alignment and key structures.

The existing railway lines connect a large part of northern Copenhagen and Zealand to the City centre of Copenhagen, the capital's airport and subsequently to Sweden via the fixed link across the Øresund, which means that they are vital for the infrastructure in the region. Consequently it was not possible to close down all lines during the construction period simultaneously. Only two extremely short main closures were allowed for at each end of the construction schedule.

Figure 2 shows a photo of the 5 railway lines taken from east towards west.

Figure 2. Picture taken prior to project start up showing the 5 railway lines.

The client (the Municipality of Copenhagen) chose Ramboll to be the client's consultants, preparing the detailed design of all permanent works, while the design of the temporary structures was chosen to be split in two parts with different premises and responsibilities.

In the central and most complex part of tunnel alignment - which means at the railway crossing - the client chose a contract form whereby the contractor (Pihl-Zueblin JV) and Rambøll should sit together and optimize the temporary structures at the railway crossing with due consideration, of course, to economy and safety, but most of all with reference to the time schedule.

In the remaining parts of the alignment (the ends) the contractor designed the temporary structures, which e.g. included retaining walls and temporary bridges across the construction pit to facilitate the main road to be open during the complete construction period.

This present paper focuses solely on the temporary retaining structures in the railway crossing which the parties - in close corporation - identified as the optimal.

2 OVERALL GEOMETRY

The vertical alignment of the tunnel is governed by the alignment of the existing rails which are not allowed to be changed. This means that the depth of the construction pit is determined from the height of the future permanent tunnel structure and a required soil cover between the railway tracks and the tunnel roof. The width of the construction pit is about 20m

Figure 3 shows a plan and a longitudinal section at the railway crossing (from St. 5075 to St. 5230).

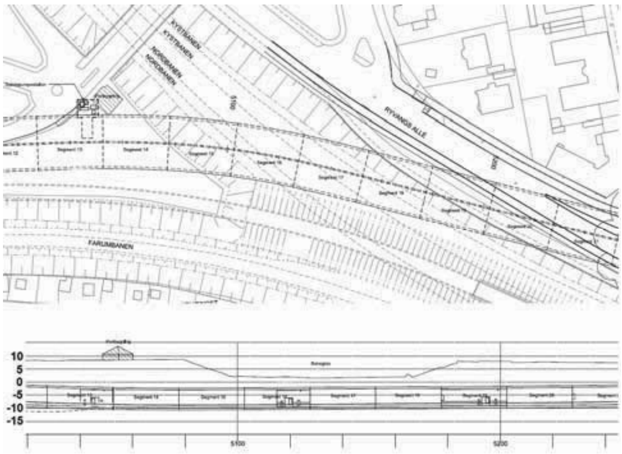

Figure 3. Plan and longitudinal section at the railway crossing.

As shown in Figure 3 the existing railway lines lies in a dell in the terrain. This dell is dug out in the glacial deposits when the railway lines were established.

3 GROUND CONDITIONS

The ground conditions at the railway crossing – and for the Nordhavnsvej project in general - are characteristic for the Copenhagen area.

3.1 *Soil*

Below a thin layer of fill, the intact soil generally consists of a 10-20m thick quaternary layer of firm clay till with encapsulated layers of melt water sand and gravel. Underneath the quaternary soils limestone is met where the upper 3m is assumed to be glacially disturbed.

As shown in Figure 4 the number of geotechnical investigations in the railway crossing is significant.

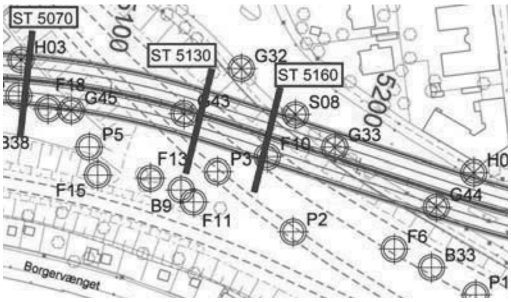

Figure 4. Plan of geotechnical investigations.

The soil parameters are determined from shear vane tests and SPTs carried out in the boreholes, triaxial and oedometer tests performed in the laboratory on the clay till, VSPs and a priori knowledge of the soil conditions in general.

The sections in St. 5075, St. 5130 and St.5160 shown in Figure 4 indicates the three cross sections being design profiles/representatives for the railway crossing. Figure 5-6 show the assumed geological strata at these three sections

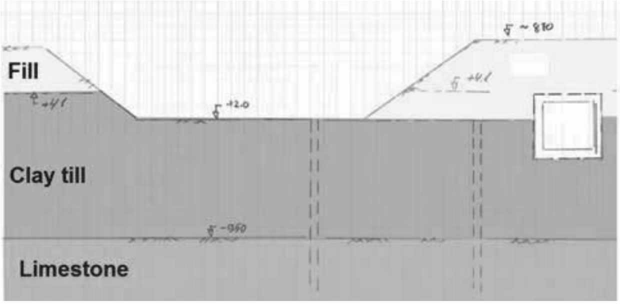

Figure 5. Geological stratum at St. 5075.

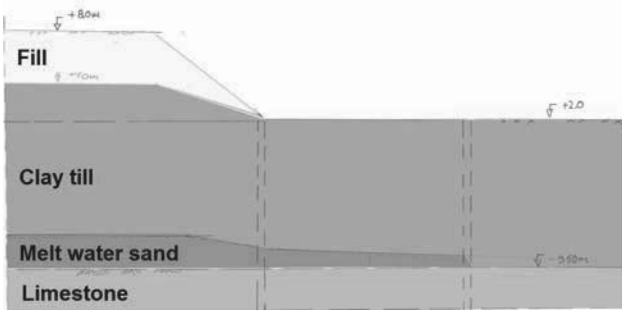

Figure 6. Geological stratum at St. 5130.

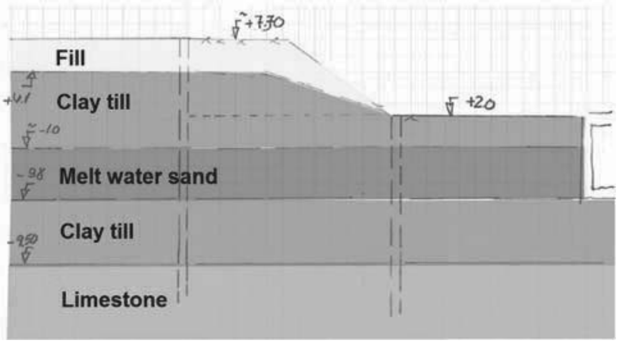

Figure 7. Geological stratum at St. 5160.

3.2 *Ground water*

At Nordhavnsvej the primary and secondary aquifers are separated. The primary aquifer is the limestone and the secondary aquifer is in the quaternary soils. The water levels are more or less coincident situated a few meters below original glacial ground level except at the railway crossing where the dell in the ground level causes the ground water level down to the terrain.

For the construction of the Nordhavnsvej tunnel it is necessary to lower the ground water level in the limestone temporarily to be able to build the permanent structures. Due to limitations on the allowance of lowering the ground water level in the secondary aquifer, a significant lowering and re-infiltration management system was established.

4 STRUCTURAL SOLUTION

Because of the requirement, that all four crossing railway lines must be in service in the complete construction period except for a few short closures, a number of different solutions to respect that were considered during the early stages of the project, including pipe arching, top down and the chosen solution, being construction of four temporary steel bridges carrying each a railway line across an open construction pit, facilitating the tunnel to be build bottom up.

Since the railway lines cross the construction pit with rather small angles, the bridge spans are between approx. 40m and 70m. The bridges are prefabricated steel bridges founded on 2-5 bored piles below each bridge placed inside the pit, the retaining walls and concrete foundations with transition slabs at each end.

For safety reasons the bridges are connected in pairs to provide footpaths. Figure 8 shows a cross section in the bridges.

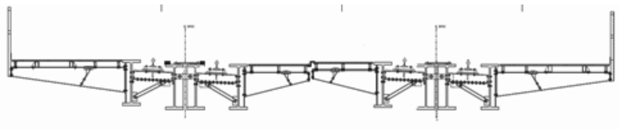

Figure 8. Cross section in temporary bridges.

The type of retaining wall is determined by the constructability in the very hard clay till and the limestone, containing significant amounts of boulders and flint respectively.

In the tender material a solution with steel sheet piles placed in a cement-bentonit slurry trench was prescribed, but during the optimization phase the contractor suggested to use secant pile walls, type hard-firm, since this method is already used outside the railway crossing and consequently well tested before constructing the retaining walls during the railway closure.

The secant piles are established with the Kelly method, cased until 0.5m below excavation level (diameter 1180mm) and below that uncased to the bottom (diameter 1080mm). The walls are staggered so that the firm piles are stopped 1.5m below excavation level. Hard piles are reinforced with 14 or 18pcs. K40 longitudinal reinforcement and K14 spiral shear reinforcement.

To avoid significant crushing works on the secant piles after establishing the tunnel, HEB profiles are casted into the top of the reinforced secant piles or the capping beam and timber lagging is used as infill, forming fixed soldier pile walls, which can easily be cut down and removed respectively. Figure 9 shows one of the encastered soldier pile walls.

Figure 9. Encastered soldier pile wall.

The support system in the railway crossing consist of two levels of walings and steel tube props, supplemented by ground anchors to balance the system where the ground level is significantly different on the two sides of the construction pit.

Where the terrain is at railway level, the upper waling is a concrete capping beam placed on top of the secant piles and attached to the piles by 5 threadbars per reinforced pile as shown in Figure 10. The solution is chosen because it is fast to wash away the upper (poor) concrete in the secant piles, place the prefabricated reinforcement cages for the capping beam and get it all casted together.

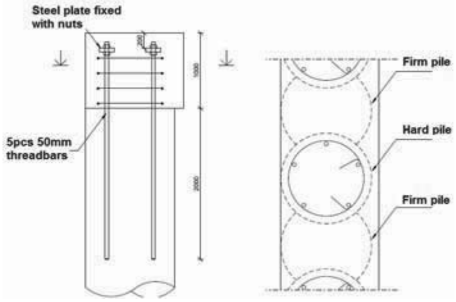

Figure 10. Connection between reinforced secant piles and upper capping beam.

The props in the upper support system are all steel types with 25mm thickness and diameters ranging from 610mm to 820mm and placed unevenly with distances of about 6-8m. The location of the props are of course governed by the capacities of the capping beams and props, but also by the location of the concrete beams spanning from the capping beam to the foundation piles supporting the rail bridges. Figure 11 shows the upper support system and support beams for the bridges and Figure 12 shows a picture of one of the support beams.

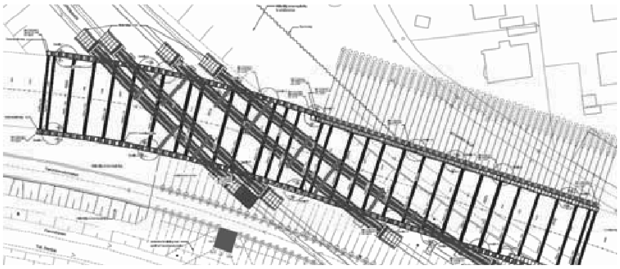

Figure 11. Upper support system and support beams.

Figure 12. Picture of support beam.

The props and walings in the lower support system are very temporary. As soon as the bottom slab of the tunnel is established, the props and walings are removed. Consequently a steel solution with double HEB-profiles and steel tube props is chosen, since the establishing and removing of this system is less time consuming than any concrete solution.

5 DESIGN

The design of the retaining walls and the support systems have been carried out using 2D numerical approaches since the effect of asymmetric loading is considerable; different terrain levels, different ground water levels and different loads on each side of the construction pit leading to props pushing excess force from one side to the other. For ULS analyses FEM have been used and cross checked with subgrade reaction models. In SLS small strain stiffness has been considered in FEM analyses.

To ensure that any 3D effects – like the partial loads from trains - were considered realistically in the 2D models, small 3D

FEM models were established and the results were incorporated in the 2D models.

Like for the geological strata, three representative structural cross sections were developed. The sections appear in Figure 13.

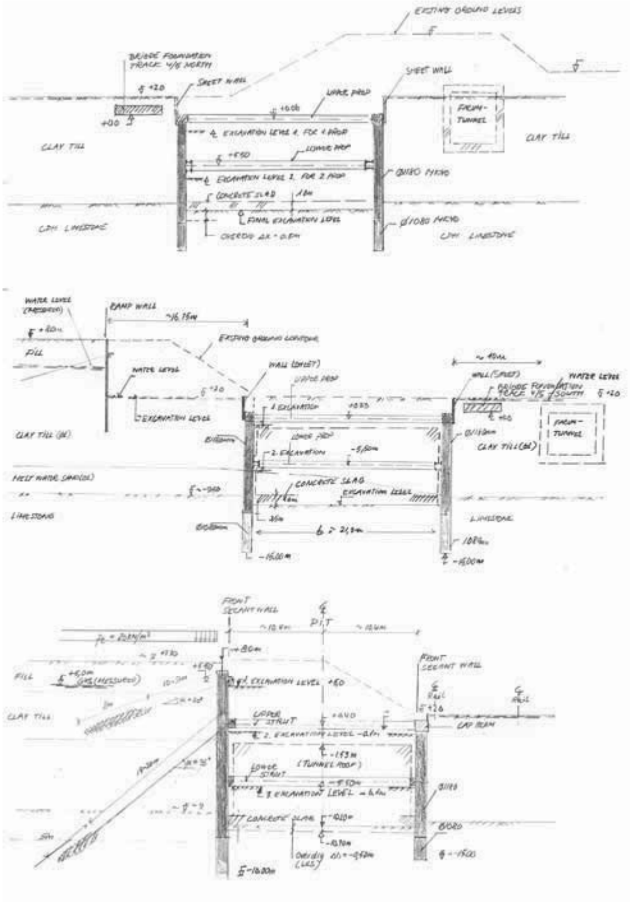

Figure 13. Representative structural cross sections.

The longitudinal reinforcement in the secant piles is checked to behave elastically in SLS, while in ULS and ALS plastic behavior is accepted. The shear reinforcement in the piles are designed using the crack sliding model for a circular cross sections, which is a further development of the plasticity-based crack sliding model originally developed for rectangular beams.

The distribution of sectional forces in props and walings are like the retaining wall design based on numerical methods, in this case spring models taking the stiffness of both the soil and the structural elements into account.

In addition to the load cases considered in the design of the secant pile walls the support systems are designed to withstand temperature loads on the props and the two ALS situations; unintended impacts from a single load and failure of a prop or anchor.

6 MONITORING

Due to strict requirements for deformations of the railway tracks and the aim to avoid structural damage to existing structures, a rather comprehensive monitoring program with accompanying action lists were developed. The monitoring includes; monitoring of rotations and deflections of the secant pile walls via measuring points and inclinometers installed on and in singled out piles, monitoring of forces in certain struts and ground anchors and monitoring of movements of foundations, railway sleepers and terrain in general. Furthermore of course the ground water heads in both the primary and secondary aquifers are monitored. All monitoring data are stored in a database.

The measured deformations and forces are continuously compared to the expected magnitudes determined in the SLS analyses. In the analyses a number of combinations of different ground water and load conditions are investigated, leading to so called trigger levels for each measuring item in each construction stage. The trigger levels are threshold values of when certain actions must be taken or measures must be done. The trigger levels are presented on a number of drawings, so that they can easily be compared to the monitored conditions on site. Figure 14 shows an example of how the trigger levels are displayed (wall deflections when excavating for establishing of the lower support system at St. 5200).

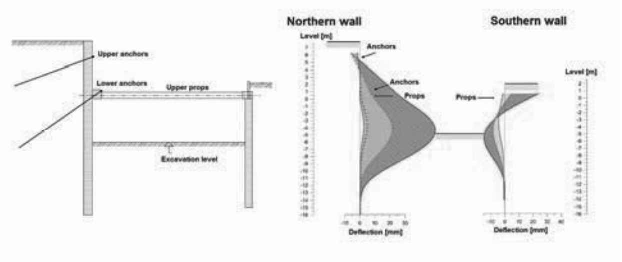

Figure 14. Example of trigger level display.

The monitoring is as a starting point performed with measurements on daily basis, but since most the measurements are performed automatically the frequency can easily be raised if any unexpected development in deformations and/or forces is recorded or lowered if no critical development is recorded.

7 CONCLUSIONS

To be able to construct the future Nordhavnsvej tunnel in Copenhagen, a construction pit with crossing railway lines and a tight construction schedule has been established.

Through corporation between Client, contractor and consultant the mission of not violating short and fixed closures was accomplished. Figure 15 shows a picture of the project stage in December 2012, where installation of the lower support system was ongoing.

Figure 15. Picture of the railway crossing, December 2012.