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Railway Tunnel under Sydhavn Station

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Summary

As a part of the Danish Landworks for the coming fixed link between Denmark and Sweden a tunnel underpassing the freight tracks near Sydhavn Station has been constructed. This paper describes the design and the construction of Tunnel Sydhavn Station, which is situated inside the Copenhagen railway freight yard. The chosen construction methods for the construction pit bracing and the ground water lowering are described along with the observed settlements of the adjacent tracks for passenger and freight trains.

1. Introduction

In March 1991 the Swedish and the Danish governments agreed to establish a fixed link across the Øresund between Copenhagen in Denmark and Malmö in Sweden. The Link will consist of a four-lane motorway, and a dual-track railway. The Danish landworks include a railway from the Central Station of Copenhagen to the coast of the Øresund near the Copenhagen Airport and an extension of the existing motorways to the coast of the Øresund. The Danish Landworks are constructed by A/S Øresundsforbindelsen (ASØ), which is a state-owned limited liability company. The total length of the railway is approximately 18 km and the total length of the new motorway is approx. 9 km. The Danish Landworks are expected to open in 1998 and the entire link in the year 2000.

2. Tunnel Sydhavn Station

In the following, a specific Contract - "Tunnel Sydhavn Station" - of the Danish Landworks is described.

2.1 Alignment

The new ASØ tracks are connected to the existing tracks at Copenhagen Central Station and pass the Central Freight Station. In the freight depot area at Enghavevej, ASØ's track will descend into the "Tunnel Sydhavn Station" and will remain in a tunnel (Tunnel Sydhavnsgade) until the main street Sjællandsbroen is crossed near the strait Kalvebod, where the railway will ascend from the tunnel, and cross the strait on a low bridge.

The design speed for the line is 120 km/h in the curve at Sydhavn Station. The tracks have a maximum gradient of 1.7% in the tunnel at Sydhavn Station and 2.44% in the ramp. The gradient is acceptable due to the fact that only passenger trains use the tracks. The steep logitudinal profile was necessary to ensure that the tunnel could underpass the street Gl. Vasbygade and still only affect those tracks which nevertheless had to be closed to make room for the ramp.

2.2 Geology

The geology of the area comprises soil infill and boulder clay in various thicknesses overlying the Copenhagen Limestone. The fill layers vary in thickness from 1 m to 8 m. The limestone is found at depths between 4 and 12 m below ground surface. The limestone is a primary aquifer which contains the ground water resource of the Copenhagen area. The undisturbed ground water level is found at approximately level 0 i.e. at sea level.

2.3 Tunnel Structure

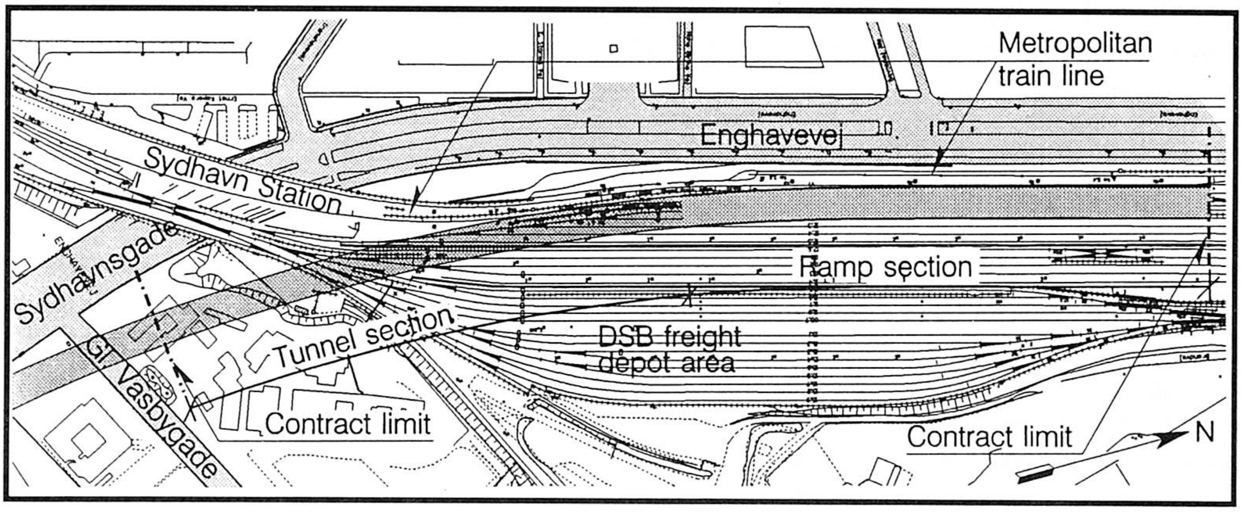

Figure 1 "Tunnel Sydhavn Station" -plan

The Contract "Tunnel Sydhavn Station" comprises 275 m of cut & cover concrete tunnel along with an 300 m anchored sheet pile ramp. The ramp section is situated inside the Danish State Railway's (DSB's) existing freight yard, while the tunnel section underpass the entrance to the freight yard very close to the Metropolitan Line Station "Sydhavn Station", cf. Fig. 1. The tunnel extend into an approximately 1,6 km concrete cut & cover tunnel running along the east side of the street Sydhavnsgade. This tunnel was constructed under a separate Contract named "Tunnel Sydhavnsgade". "Tunnel Sydhavn Station" was constructed by a Danish consortium HPA (a joint venture of the companies Højgaard & Schultz A/S, Pihl & Søn A/S and Per Aarsleff A/S) on the basis of a main project prepared by R/N (a joint venture of the consulting engineering companies RAMBØLL and Nellemann, Nielsen & Rauschenberger A/S). The contract sum was approximately USD 15 million, and the work took place from September 1994 to December 1996.

In the initial planning phases of the railway in the Sydhavnsgade area, the tunnel was assumed to be carried out as an open dewatered structure. But out of concern for the groundwater level in Copenhagen and the existing winnings in the area the initial decision was altered after the finalization of the preliminary geotechnical investigations and the tunnel was instead constructed as a cut & cover tunnel made of watertight concrete with drained sheet pile ramp.

Several solutions for the passing of the tracks at Sydhavn station were considered in the initial planning phase. Tunneling was not assumed possible due to the lack of sufficient overburden. Likewise tunnel jacking had not been tried in Denmark for a tunnel with this large cross section, a length of almost 300 m and an overburden between 0.5 m and 4 m. As DSB accepted that the tracks could be closed for shorter periods if the closings were planned and coordinated with DSB, it was decided to construct the tunnel as an cut & cover tunnel.

The internal height of the tunnel is approximately 6.5 m. The internal width is approximately 11 m. The walls have a thickness of 0.7 m, the roof is 0.75 m to 0.9 m thick and the bottom is 0.75 m to 1.0 m thick. The width of the tunnel base slab exceeds the tunnel width. This safeguards the tunnel against uplift. The tunnel walls and -roof are covered by a bentonite membrane of the type DUAL SEAL.

In both sides of the tunnel there is a combined cable canal and pedestrian walkway, which serves as an escape route in case of an accident in the tunnel.

3. Construction Requirements

3.1 Planning requirements

The entire work area for the Contract was situated within the existing railway yard. Thus, there was very little space available and all works had to be planned with due consideration to the safety regulations for tracks and catenary systems in operation. The train traffic on all railway tracks should maintain a full schedule during the construction period. In the tender documents, it was stated that the tracks could be closed in weekends agreed upon. The time periods were dependent on the tracks in question.

3.2 Design of the construction pit

Functional requirements for design and execution of the construction pit bracing were given in the tender documents, as temporary structures in Denmark are normally designed and constructed by the contractor no matter if the permanent structures are constructed in accordance with the owner's design or according to the "design and build" principle.

The construction pit for the “Tunnel Sydhavn Station” was situated very close to existing track areas. The construction pit bracing was thus constructed to meet the highest safety requirements. Normally, 20 kN/m^2 are estimated as the surface load when designing retaining walls adjacent to trafficked areas. For "Tunnel Sydhavn Station", the pit walls were designed for train loads on the tracks crossing or running along the bracing giving loads of more than 50 kN/m^2.

To reduce the settlements in the area behind the retaining wall, the construction had to be planned and executed in a such a way that no voids occurred behind the wall. Furthermore, it had to be documented by calculations that no point on the wall would have a horizontal deflection exceeding 10 mm for the upper 3 m of the wall and 50 mm for the lower parts of the wall. The contractor still being responsible for settlements in the area behind the retaining wall.

4. Construction Experience

4.1 Construction Progress

In connection with the execution of the construction pit for the tunnel, a cover was to be provided in the areas, in which the tracks should overpass the construction area. In his design, the Contractor, preferred a simple connection between the interim cover and the pit walls. The cover consisted of steel plates on HE1000B profiles every 1.2 m. and the walls were constructed as anchored Berlin walls with profiles per 1.2 m. As filling between the profiles, steel plates were used for the upper 3 m of the wall. They were pressed down in connection with the driving of the profiles, i.e. before placing the cover. For the remaining part of the wall, the filling was constructed by shotcreted concrete arches with a minimum thickness of 5 cm cast concurrently with the excavation.

Driving the steel profiles was mainly done during 6 weekends in Autumn/ Winter of 1994/95. The train traffic was diverted to other tracks in these weekends, so that the tracks could be removed to establish room for the pile drivers. During 3 weekends in the Winter of 1995, the tracks were again removed, so that the interim cover could be established.

After finishing the interim cover, the Contractor excavated along the whole tunnel length to a level corresponding to the lower edge of the steel plates. Hereafter, the contractor was allowed to excavate up to a height of 1.5 m (depending on the ground conditions) immediately after which the shotcreting between the profiles should be performed. No uncovered soil surface was allowed after working hours and furthermore the excavation was inspected every night around 1.30 a.m. during the entire excavation period.

After finishing the concreting and the membrane works, the Contractor backfilled the excavation to a level just below the interim cover.

Finally, during 2 weekends in September and October 1996, the tracks were again removed and the steel profiles cut minimum 1 m below the lower edge of the sleepers, after which the remaining backfilling was performed and the tracks relayed.

ASØ had in the Contract stipulated compliance with ASØ´s general environmental management system prepared on the basis of BS 7750. Based on this general system, the Contractor should prepare a detailed environmental action plan, which comprises the special procedures concerning the environmental issues of the Contract. For details about the environmental requirements and the monitoring see (Hess et al., 1996).

4.3 Monitoring of Settlements

The execution of the deep construction pit was expected to cause settlements in the areas close to the retaining walls. This would be caused by the driving of HEB-profiles and by the deflections of the retaining walls during excavation of the pit. Furthermore the extensive groundwater lowering was expected to cause settlements in the fill layers.

Within the railway yard adjacent to the excavation, daily monitoring of the settlements of the nearby tracks for the Metropolitan Train Line was required by DSB, in order to secure that the train traffic was not adversely affected by differential settlements of the rails. The rails for the freight trains were monitored less frequently, about once a week. Settlements of max. 30 mm due to the deflection of the retaining wall were foreseen in the design.

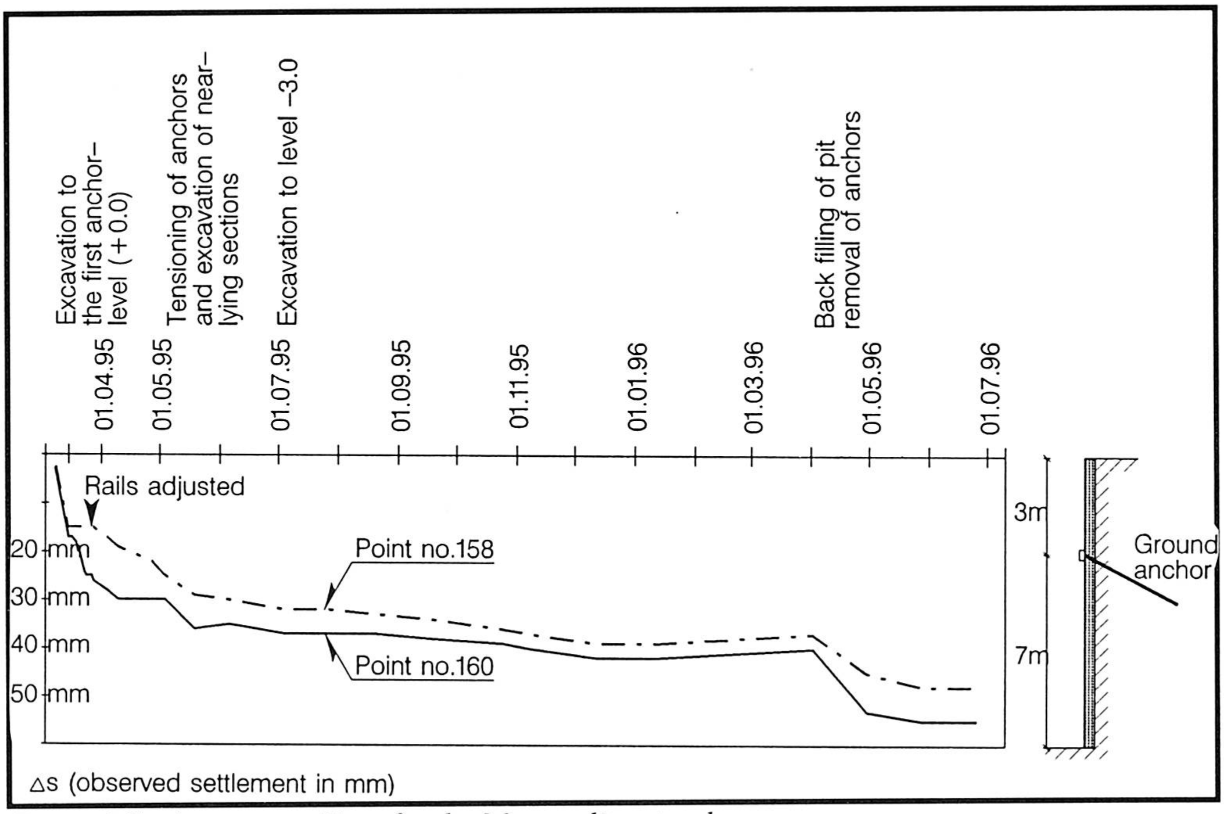

Figure 2 Settlements vs. Time for the Metropolitan track

Daily settlement monitoring on approximately 30 measuring points was performed during excavation of the construction pit and furthermore, the tracks for the Metropolitan train were surveyed by DSB personnel during all operating hours. In Fig. 2, the development of the settlements during the excavation and backfilling process is shown for two selected measuring points placed directly on the rails very close to the construction pit (less than 2 m from the edge). The maximum settlements of the track amounted to 55 mm. More than half of the settlements developed during excavation to the first anchor level. After the first quite dramatic settlements, it was necessary to adjust the rails, but after tensioning of the anchors, the progress of the settlements slowed down considerably. The settlements increased again when backfilling of the tunnel and removal of the anchors were performed.

The settlements of the freight tracks were between 2 and 30 mm dependent on the distance of the measuring point from the excavation.

5. Groundwater Lowering and Monitoring

At Sydhavn Station the dewatering was performed through 10 12 inch filter wells, all drilled to approx. 22 m below ground level (10 - 12 m in the limestone) outside the Berlin walls. The site was situated in an area close to an existing groundwater abstraction and therefor the dewatering was carried out with a high degree of adjustment to the actual excavation level. In the tender documents it was stated that the ground water level only was allowed to be lowered to 2 m below the deepest excavation level.

The groundwater lowering system operated in 77 weeks starting in November 1994 and stopping in July 1996. In this period approximately 44 m^3/h was pumped from the primary aquifer (the limestone), approximately 72 m^3/h at the beginning of the period and approximately 25 m^3/h at the end. In total approximately 600000 m^3 of groundwater was pumped up.

To evaluate the effects on the surroundings in the construction and the permanent phase a 3-D ground water model had been established by use of MIKE-SHE (Systéme Hydrologie Europépne). On the basis of the MIKE-SHE model a monitoring programme was planned with the following objectives:

- to register the amounts of water pumped up.
- to monitor changes in the ground water level around the site.
- to monitor possible chances in the natural ground water chemistry.
- to register chances in the dispersion of conterminants in the ground water reservoir.

For details about the MIKE-SHE model see (Hess et al., 1996).

In the permanent phase it is necessary to relieve the ground water pressure in the deep end of the sheet pile ramp. Thus 3 permanent 10 inch bleederwells approximately 10 m deep (5 m in the limestone) have been established. Only the well in the deepest end of the ramp yields water, the amount is not systematically registered.

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