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Cut-and-Cover Tunnels at the Arlanda Link

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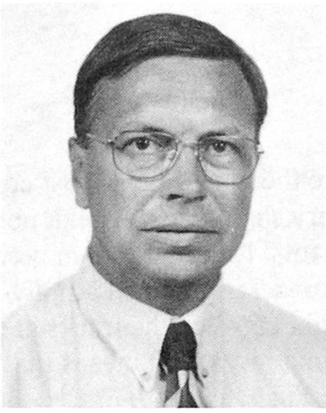

Magnus Mörnstad, born 1944, received his civil engineering degree at Lund Institute of Technology in 1969

Summary

The Arlanda Link is a new high-speed train connection between the centre of Stockholm and Arlanda Airport. A railway of about 20 km will be designed and constructed in the project. In the airport area the railway runs below ground surface. The underground sections have a total length of about 5 100 metres and include four cut-and-cover tunnels. Due to different loading and geotechnical conditions the cut-and-cover tunnels are designed in different shapes. This report covers the predominating design considerations.

1. Introduction

The Arlanda Link is a new high-speed train connection between the centre of Stockholm and Arlanda Airport. The project commenced in June 1995 and is scheduled to be completed for commercial use in the end of 1999. It is estimated that the project will cost about 4 700 million SEK (=650 million USD) including construction works, tracks, signal systems and shuttle trains. With this new connection the travelling time from the centre of Stockholm to the airport will be reduced from 45-50 minutes to only 20 minutes.

This BOT-project (Build-Operate-Transfer) is directed by a joint-venture company esablished by GEC ALSTHOM, NCC AB, and John Mowlem Construction AB. The joint-venture company has in turn established A-Train AB, a company which will operate the traffic on the Arlanda Link until 2040.

The project includes the design and construction work of a railway of approximately 20 km length, running from the main line at Rosersberg via Arlanda Airport and reconnecting with the main line at Odensala. In the airport area, the railway will run below ground surface. The underground section has a total length of about 5 100 metres and includes rock and concrete tunnels as well as three train stations integrated in the airport terminals. In this part, four sections of cut-and-cover tunnels will be constructed :
Section 1: The Märsta River Tunnels; Inter-city Tunnel (L=318 m) and Shuttle Tunnel (L=437m)
Section 2: The Åsa Tunnel (L=175 m)
Section 3: The Brunnby Tunnel (L=232 m)
Section 4: The E4/65 Tunnel (L=150m), (equal to the Inter-city Tunnel as mentioned in section 1 and not to be described in this report).

All cut-and-cover tunnels in sections 1-3 are connected to rock tunnels at both ends. Due to different loading and geotechnical conditions the tunnels are designed in different shapes. This report covers the predominating design considerations.

2. General

2.1 Tunnels below the Märsta River

The tunnels below the Märsta River are the longest and most complicated. This section involves two tunnels crossing each other at a very sharp angle. The double-track tunnel for inter-city trains is located at the lowest level and has a total length of 318 m between the connections to the rock tunnels. The single-track shuttle-train tunnel is designed as a fly-over and has a length of 437 m. Depending on a very low available height between the tracks at the fly-over point, the two tunnels had to be integrated for a length of 75 metres, which means that the roof slab in the lower tunnel serves as bottom slab in the upper one, Fig 1.

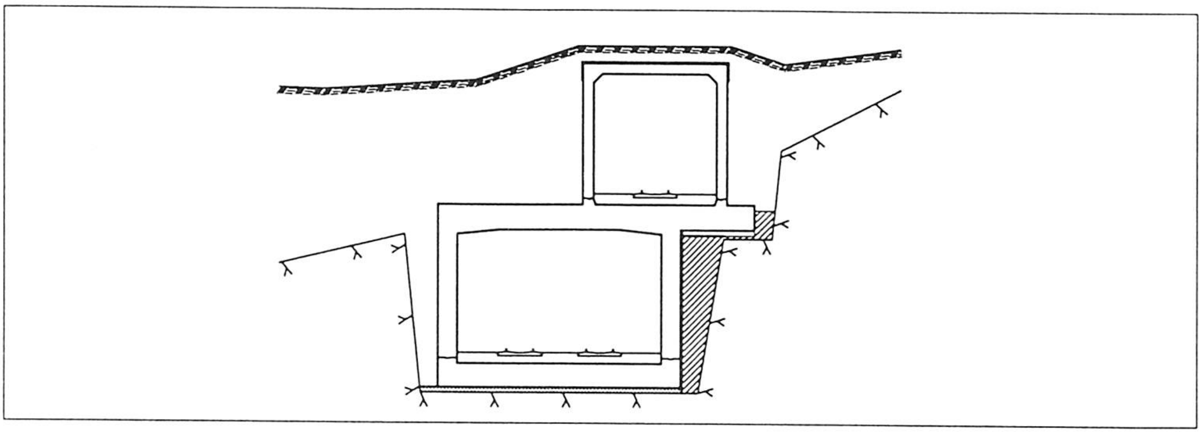

Fig 1 : Fly-over tunnels below the Märsta River

The double-track tunnel has an internal width of 11.50 m and a total internal height of 7.50 m. The wall thickness is 1.10 m, the bottom slab 1.35 m and the thickness of the roof slab varies from 1.05 to 1.35 m. The internal width of the shuttle-train tunnel is 7.00 m and the height is 7.30 m. The roof slab and the walls are 0.65 m thick. The bottom slab has cantilevers to prevent water uplift, Fig 2.

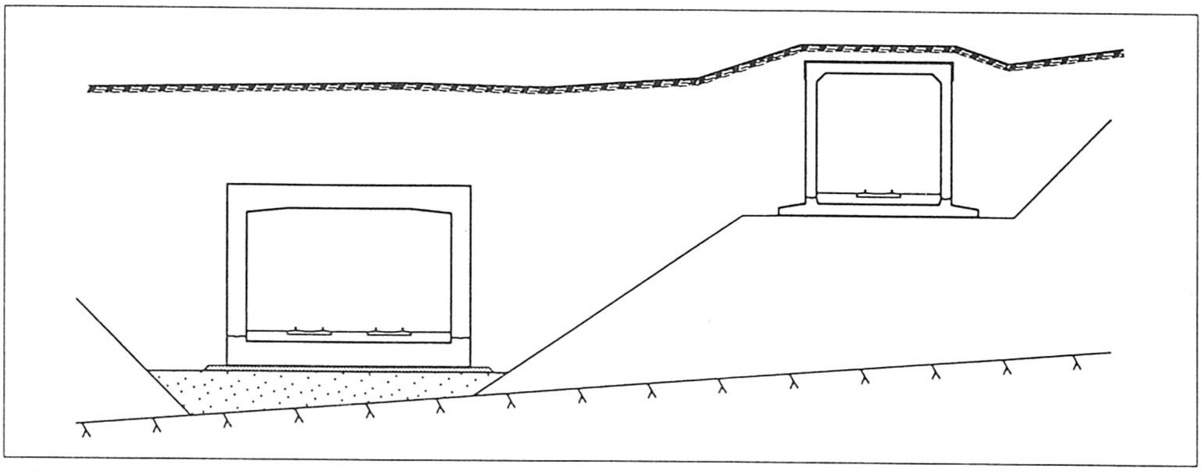

Fig 2 : Tunnels below the Märsta River

2.2 The Åsa Tunnel

The cover of the Åsa tunnel, which is 175 m long, is arch shaped with a radius of 7.50 m as seen in Fig 3. This is the lowest point of the tunnel and the tickness of the covering filling masses is up to 20 m from the top of the arch to the ground surface. The arch has a fixed thickness of 0.65 m and rests on rock shelves about 2.50 m above the track level.

At an early stage it was considered to build this section in accordance with the so called "Spiling-method", which is adviceable when very deep earth excavation work is required and there are ground surface accessibility restrictions. However, due to bad geotechnical conditions in the area, these plans had to be changed to cut-and-cover tunnel.

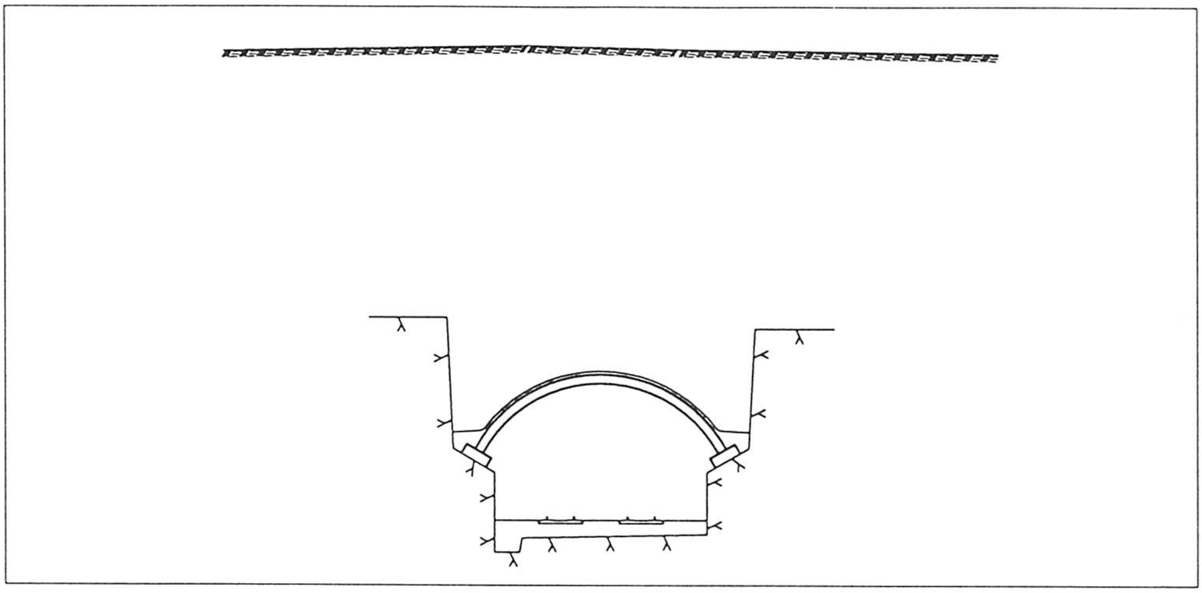

Fig 3 : The Åsa Tunnel

2.3 The Brunnby Tunnel

The Brunnby tunnel is 232 metres long and located in the northern area of the airport just before the railway reaches ground level, Fig 4. Due to low filling thickness, the loading on this tunnel is less heavy and it was possible to minimize the dimensions of the superstructure. Different analyses indicated that a shape with leaning walls close to the roof slab was the most advantageous construction. Wall and roof slabs are 0.70 m thick. Whilst the internal width is the same, the height had to be increased to 7.75 m to accommodate train inclination.

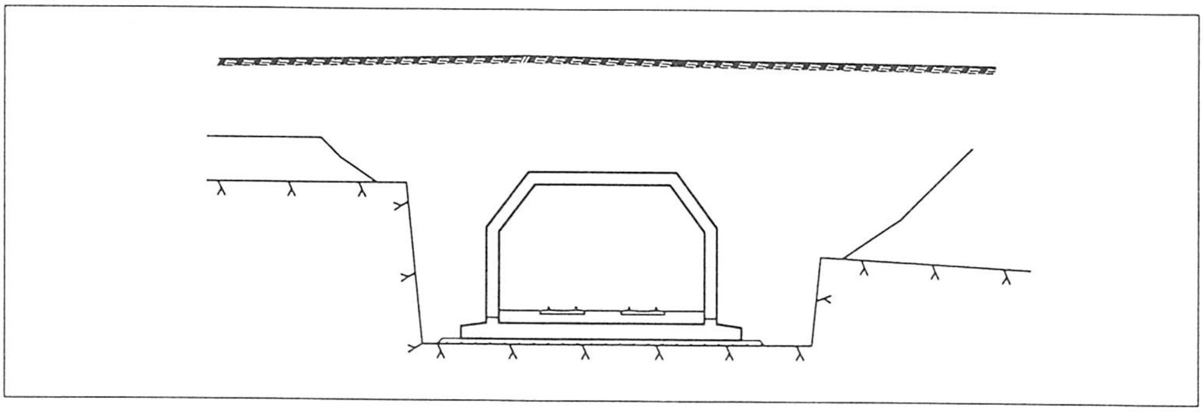

Fig 4 : The Brunnby Tunnel

3. Geotechnical Conditions

3.1 Tunnels below the Märsta River

In this area the railway is passing underneath the Märsta river. The river valley runs in an east-westerly direction and is about 500-600 meters wide. The northern and southern areas of the valley consist of steep mountain sides and the thickness of rock is sufficient to allow construction of rock tunnels.

In the mid section of the valley, the soil consists of 3-7 m clay. The clay has a dry solid top layer and underneath it is very soft with a shearing strength between 11 and 14 kPa. The clay layers are resting on moraine with varying thickness between a few metres and almost 20 m. In some areas the moraine top layer is comparatively soft but lower layers are very hard. Rock surface has been discovered about 21 m below the ground surface at the lowest point. The mean ground water level is 16 m above the foundation level.

The foundation of the lower inter-city tunnel is mostly built on a layer of compacted blast stones on the rock. In the middle of the valley, the foundations of some sections of the tunnel had to be built on moraine, which is at most 3-4 m thick. In the southern section, the foundation of the shuttle tunnel is integrated in the roof slab of the inter-city tunnel and in the northern section built on a 10-12 m thick moraine layer. In the surroundings of the fly-over point, the backfill is made of concrete in order to avoid vertical settlements. In the northern section the foundation is built on compacted blast stones on the rock.

The excavation work started with preventive reinforcements of the clay layer. About 20 percent of the clay volume had to be reinforced with lime-cement pillars. As a result of this, the shearing strength increased by approximately 100 percent. Afterwards the excavation work could be carried out at a mean inclination of the slope by 1:1. Lowering of the ground water level is effected by pumping in wells. Because of difficulties in lowering the ground water level in the impermeable moraine layer, some problems occurred during the excavation work. When the excavation work reached about one metre above the final depth of the foundation level, it was temporaraily stopped to make it possible to verify the solidity of the moraine layer with ram penetration tests.

3.2 The Åsa Tunnel

In this section the railway will pass through a very low depression in the rock and sufficient rock cover does not exist for a distance of 175 m although the surface of the rock is located at a higher level than the foundation level. The top soil consists of an eight metres thick layer of soft clay with a shearing strength between 12 and 16 kPa. The clay is resting on moraine with thickness varying between 8 and 10 metres. The upper moraine layer is moderately soft while lower layers are very hard. The ground water level is normally at the same level as the ground surface.

The excavation work to great depth could not be accomplished without supporting the ground. This was carried out by steel sheet piling through the clay, five metres of soil-nailing and below that "Berliner-piling" through the moraine. Due to the risks of getting settlements in the area close to the airport runways it was not possible to lower the ground water level. Therefore, water had to be recharged for infiltration around the excavation area.

To achieve accurate size and shape of the rock shelving, the blasting operation had to be performed very carefully and reinforcement bolting was necessary for stabilization. The joint between the foundation of the arch and the rock surface will be tightened with cement grout.

3.3 The Brunnby Tunnel

Also in this section the railway is passing through a minor valley. Due to a depression in the rock, a rock tunnel was not possible. In the middle of the valley, the top soil consists of a 3-4 m thick layer of peat and mud resting on an 8 m thick layer of soft clay. Underneath, there is a 1-6 m thick layer of gravelly moraine. The lowest rock surface level is located 12-14 m below the ground level. The mean ground water level is at the same level as the ground surface.

Before the excavation work started, layers of blast stones had been forced down through the soft top soil layers serving as embankments. It was then possible to carry out the excavation work through the moraine with a slope by 1:1 between the embankments.

The basis of the foundation of this tunnel section is a layer of compacted blast stones on the rock.

4. Design of and Actions on Structures

The structural design of the tunnels is based on actions, combinations of actions and safety factors according to Swedish codes BRO 94 (general rules for road bridges) and BV BRO (general rules for railway bridges).

Permanent actions are specified as:
- self-weight of concrete structures and ballast
- earth pressure from backfill of compacted moraine
- future filling to a higher level in the airport area
- water pressure
- loads from future buildings, 40 kN/m2
- imperfections
- shrinkage

Variable actions are specified as:
- railway loads in the tunnels
- traffic loads on the ground level
- aircraft loads, 80 kN/m2
- variation of ground water level
- temperature variations
- temporary crane loads during erection

Accidental actions are specified as:
- impact from derailed vehicles
- explosion, 70 kN/m2
- fire

5. Material properties and durability

The tunnels are designed to meet the requirements of an adequately durable structure with respect to its service life of 120 years. The concrete mixes are based on ordinary Portland cement with low temperature development and added with 5% silica fume. The water-binder-ratio of the concrete is maximum 0.50, corresponding to strength classes K40/45. To achieve a sufficient salt-frost resistance, the air volume is determined to at least 5%.

The reinforcing steel applies to grade K500 with characteristic yield stress fyk=500 MPa. The minimum concrete cover is determined to 45 mm. Cracking is limited to 0.2 mm under service actions in structures exposed to water pressure. With respect to reinforcement corrosion the crack width may not exceed 0.3 mm.

6. Detail Arrangements

The structures are arranged in 15 m sections separated with expansion joints. However, in the fly-over area, the section is determined to be 75 m long to avoid oblique-angled slab elements. The expansion joints are provided with two separate PVC-waterstops and an extra volclay sealing. The construction joints between the bottom slab and the walls are provided with a single waterstop and an injection hose for epoxy injection, if necessary. In cases where the tunnels are based on moraine layers, the expansion joints are designed to withstand even perpendicular movements.

7. Construction Methods

The 15 m tunnel sections are cast in two stages. The bottom slab is cast in the first stage and the wall and roof slabs are cast simultaneously in the second stage. To avoid cracking in the walls due to temperature differences between the previously cast bottom slab and the walls, special arrangements were required:

1. appropriate concrete mixes with a minimum content of cement/binder
2. cast-in heating cables in the bottom slab
3. insulation
4. cast-in cooling tubes in the walls

The temperature progress is measured continuously by cast-in temperature gauges and the data is transmitted by radio to a computer in the site office to enable immediate actions in case of undesireable temperature differences.

The steel reinforcement has been prefabricated in large cages and is placed in the formwork by crane.

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