Foundation for the Uddevalla Bridge

FOUNDATION FOR THE UDDEVALLA BRIDGE

Ingmar SVENSK
Vice President
Skanska Teknik AB
Göteborg, Sweden

Ingmar Svensk is head of the department for Soil Mechanics and Foundation Engineering within Skanska Teknik AB, a subsidiary of Skanska AB, Sweden

Per-Ola SVAHN
Technical Manager
Bridge department
Skanska Anläggning AB
Göteborg, Sweden

Per-Ola Svahn is technical manager for the project Uddevalla bridge. He is employed by Skanska Teknik AB

SUMMARY

The Uddevalla bridge, which is located approximately 80 km north of Gothenburg in Sweden, is an important part of the work to upgrade the E6 high way between Malmoe and Oslo to a motorway standard. The bridge has a total length of 1712 m and is composed of a cable-stayed bridge with two approach bridges. The main span has a length of 414 m.

The Uddevalla Bridge crosses both a major fjord and a small creek on the Swedish Westcoast. The geological conditions vary in a dramatic way. Soils formed during the last deglaciation extensively covers the solid rock. However rock surfaces are also occurring.

Parts of the bridge are founded in an end moraine with more or less firm silt, sand and gravel. The thickness of the till varies between 30 to 60 m. Foundations on footings as well as precast friction piles are used. The southern tower is supported by 106 steel pipe-piles with diameter 700 mm driven almost down to solid rock. The northern tower as well as some of the northern supports are founded directly on the rock surface. In the creek postglacial soft soils with organic clay and silt overlay glacial clay silt and sand deposits to a depth which varies up to 80 m. Steel pipe piles and steel core piles were used for the foundation of the supports placed in the creek.

The impact of the environment was a major consideration for the foundation work. Excavation in water is restricted in time and space with respect to the waste of sediment. The most determining requirement is however the maximum noise level in the surrounding area of buildings. To complete the pile driving it was necessary to make some extraordinary measures to reduce the noise level.

All foundation work was performed between August 1997 and March 1998 and the bridge will be opened for traffic in May 2000.

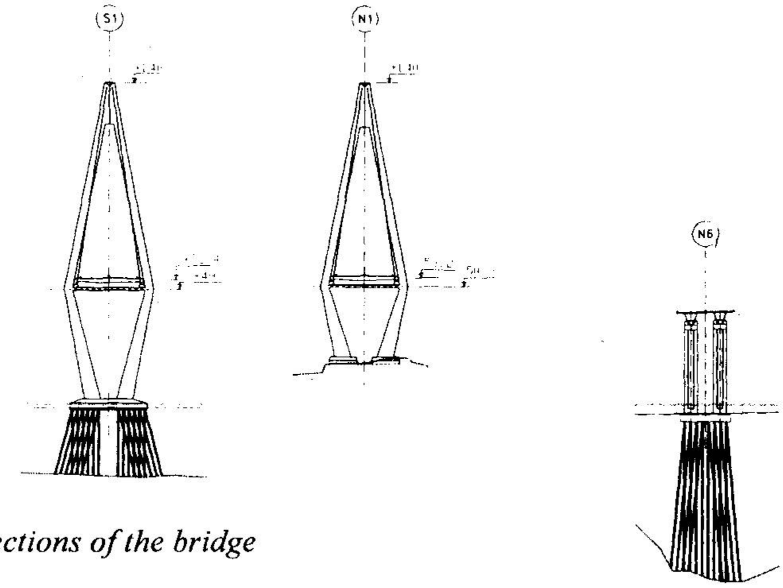

Figure 1b Sections of the bridge

Soil Conditions

The main span for the Uddevalla Bridge crosses the fjord "Byfjorden", while the northern approach bridge crosses the small creek "Kroken". The ground level above the water surface varies along the bridge from ±0 to + 37 m.

The soil layers along the southern approach bridge are parts of an end moraine. This formation has a length of about 2 km and a width of about 500 m. The supports S11, S10 and S9 are all placed in the central parts of the frontal moraine. To the north of these supports the bridge is located towards the western side of the centre of the end moraine. S8 to S5 and the southern tower S1 are thus founded in the western outer parts of the end moraine.

The northern part of the frontal moraine lies under water and forms the threshold of the fjord towards the sea. The frontal moraine was created during the last glaciation when temporary breaks occurred in the ice melting. The deposit was formed along the ice margin during a period of 100 to 200 years around 12 500 years ago. In a limited area moraine, silt, sand and gravel accumulated in one or several ridges in front of the ice. Fine-grained soils also sedimented when melt water from the ice flowed out at the ice front. Later when isostatic uplift occurred, the frontal moraine was exposed to waves and wave-wash, thus the soils vary in a dramatic way across the frontal moraine.

The thickness of the till, south of the fjord, varies between 30 to 60 m. Depth down to solid rock and its variation is indicated in figure 1. Sand is the dominating soil type down to 25 á 35 m depth. From S6 and north the sand is silty in the surface layer. The sand overlays silty clayey moraine.

The soil is dense to very dense at the location of S11, S10 and S9 according to results from hammer soundings. Further north the sediments are very loose to loose down to 10 á 15 m depth. Underneath these loose sediments the soil is dense to very dense.

North of the fjord where the northern tower is founded rock surface occurs. The rock type is mica rich gneiss.

The supports N5, N6 and N7 are placed and founded in the small creek. The water depth in the creek is limited to about 3 m. The depth down to solid rock is however up to 80 meters. Great variations in depth occur, as can be seen from figure 1, and locally the rock surfaces form very steep slopes. In this area the soil consists of postglacial sediments down to 20 m depth and

Introduction

The E6 highway between Oslo in Norway and Malmoe in the southern part of Sweden has during the last ten years been continuously upgraded to a motorway standard. The highway acts as an important link for the communication from Scandinavia to Europe.

One critical stretch is the by-pass of Uddevalla, which is located in the end of a deep fjord. The existing road passes east and through the central part of Uddevalla. After extensive investigations during the last thirty years it was decided that the new road will pass west of Uddevalla.

The new route is approximately 9 km and will save 12.8 km in total length for the road E6. However the route passes through very sensitive locations. The southern side of the fjord has both archaeological and geological values which are classified as of national interests. At the northern side of the fjord there is a location of established dwelling houses, which partly interfere with the suggested route.

The Swedish Road Administration performed a conceptual design and the tender work started in May 1996. The accepted tenderer was the Swedish contractor SKANSKA and the Design and Build contract was signed in January 1997. Structural and geotechnical design was performed by Skanska Teknik. The design work started immediately and the construction works started in August 1997. The bridge will be opened for traffic in May 2000.

The Bridge

The bridge has a total length of 1712 m and comprises of three different parts. The southern part is an approach bridge with a length of 506 m. The central part is the main bridge with a total length of 772 m and finally the northern part is an approach bridge with a length of 434 m. The bridge width is designed for a four lane motorway, i.e. a free width of 11.25 m in both directions.

The two approach bridges are composed of two parallel steel box girders with an upper composite slab of concrete. Each girder is supported on six piers and one abutment. The two piers for a support are normally founded on one common footing. The foundation is performed with footings on soil, solid rock or piles.

The main bridge is a cable stayed bridge having a main span of 414 m and two side spans of 179 m each. The superstructure is a steel grid with a composite slab of precast concrete. The two towers have a height of 140 m above the sea level. The towers are built in concrete using self climbing formwork. The southern tower is founded on piles and the northern tower is founded on solid rock.

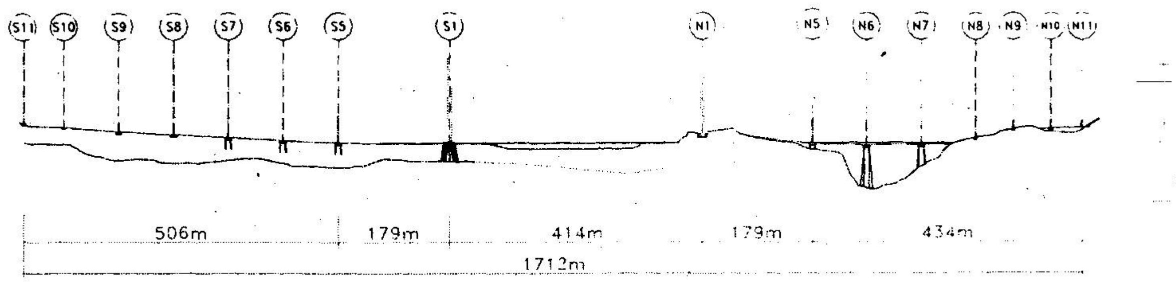

Figure 1a Elevation of the bridge

underneath follows glacial sediments. The postglacial soils are in the surface layers sand with gyttja, clay and silt. The dominating postglacial soil is however loose clay. This clay is described in figure 2. The glacial sediments are sand and clay with sand layers.

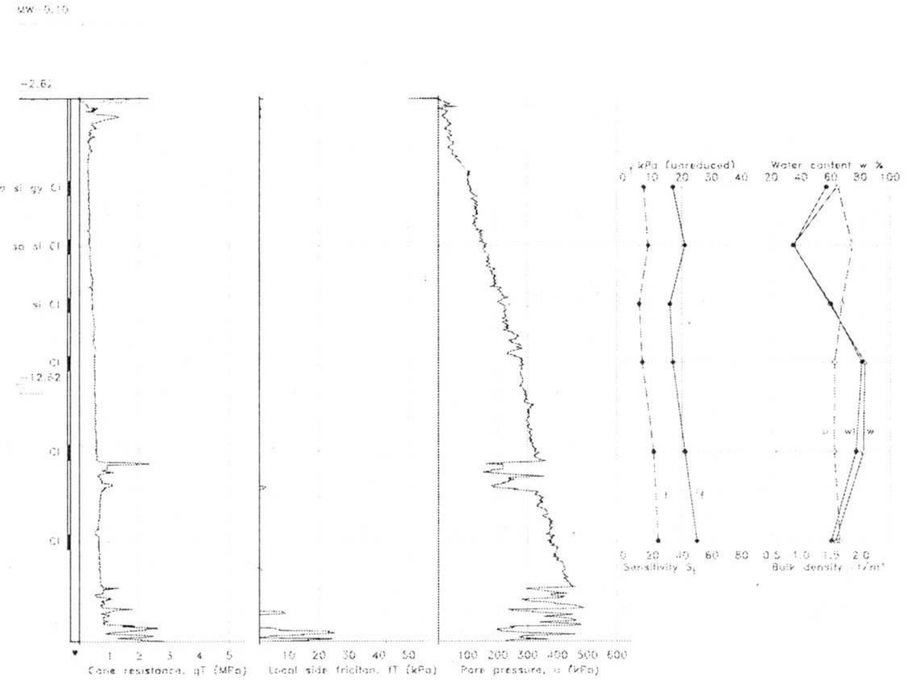

Figure 2 CPT-results and results from laboratory investigations at support N6

North of the creek the rock surface is dominating along the bridge line. However, in the vicinity of support N10 thin soil layers occur locally. The rock type is mica rich gneiss near the creek and north support N8 the rock type is massive granite.

Foundation

The supports S11, S10, S9 and S8 are founded directly on soil with footings with an area of about 10x20 m^2 each. The original loose soil under the slabs for S10 and S8 was exchanged for compacted gravel down to 3 m respectively 1 m depths. S11 and S9 were however founded directly on the original soil. Maximum vertical settlement calculated in serviceability limit state is 50 mm for these four supports founded with footings .

The supports S7, S6 and S5 were founded on driven friction piles. Precast concrete piles with square cross section 350x350 mm were used. Approximately 70 piles were driven for each support. Pile capacity was determined with dynamic testing including stress wave measurements. A Pile Driving Analyzer was used together with strain gauges and accelerometers attached to the pile head. CAPWAP analysis of the measured signal was performed to determine the static pile capacity and its distribution along the shaft and on the toe. Approximately 10 % of the piles were tested. Pile lengths varied between 8 to 26 meters.

The southern tower, S1, is supported by 106 steel pipe piles having a diameter 711 mm. The wall thickness of the pipe is 14,2 mm. The pipes were driven almost down to solid rock and then filled with concrete. Foundation for S1 with steel pipe piles was originally proposed by the client in the conceptional design. Bored piles were suggested by the contractor in the tender as an option. However, the client favoured steel piles. Pile capacity was determined by dynamic testing in accordance with the same procedure as for the concrete piles. The required pile capacity in ultimate limit state is 4500 kN. Calculated vertical deformation in serviceability limit state is 7 mm. The very limited deformation is due to the fact that most of the pile capacity origins from the toe located near solid rock.

The northern tower, N1, is founded directly on the solid rock. Maximum allowed rock pressure in ultimate limit state is 3,9 MPa.

The support N5 is founded with 41 steel core piles drilled down into solid rock. The steel core diameter is 150 mm and 210 mm for some of the piles and the pile capacity is 2500 respectively 3600 kN in compression. In tension the required pile capacity is 800 kN for both types of piles. The steel core is surrounded by a steel-pipe filled with concrete.

The two supports N6 and N7 in the small creek are both founded on driven steel pipe piles filled with concrete. About 50 piles were used for each support. The pile diameter is 508 mm and the wall thickness is 14,2 mm. The pile capacity is 2250 kN. The piles are driven down to the rock surface and thus end bearing. Due to the steep rock surface the toes for 15 % of the piles are secured with a dowel drilled into the rock. Dynamic testing was used for determining the pile capacity.

The supports N8, N9 and N11 are founded directly on the rock surface.

The support N10 rests on a footing founded on compacted fill lying directly on the rock surface. The thickness of the fill is up to 7 meters. The compacted fill consists of friction material.

Performance of the foundation work

The available time for construction is very short. Therefore it has been necessary to start the foundation works for several supports simultaneously. These works started in August 1997 and were completed in March 1998.

As mentioned in the introduction the bridge is placed in a very sensitive environment in many respects. Foundation works in general have a significant impact on the surrounding area. Noise, pollution and destruction of archaeological and geological values are common negative effects. To avoid these effects the contractor has had to present and follow, for Swedish regulations, an extensive environmental plan. The performance of the foundation work has been strongly influenced by this plan. The requirement for maximum noise level is based on an equivalent noise level, L_{Aq}, in dB(A). The requirements for different times during a week are shown in the table below. $L_A(t)$ is the noise level in dB(A) at time t.

	Mon-Fri 07-18	18-22 & Weekends	22-07
Dwelling houses	$L_{Aq} \leq 60$	$L_{Aq} \leq 50$	$L_{Aq} \leq 45$

$$L_{Aq} = 10 \cdot \log \frac{1}{T} \cdot \int_0^T 10^{\frac{L_A(t)}{10}} \cdot dt \text{ [dB(A)]}$$

The southern approach bridge is founded with footings and piled foundations. The piling work started in a support close to the core of the end moraine (S8). The support was originally designed with friction piles. However the piling work was soon interrupted because it was impossible to continue the work without destroying the concrete piles during the installation.
After additional geotechnical investigations it was decided to change the foundation to a footing founded directly on the soil. The remaining supports are performed in principal according to the initial design.

The two towers for the main bridge are founded with footings on steel pipe piles and solid rock. The installation of the 106 steel pipe for the southern tower were assumed to imply an extensive pile driving. The work was planned to be performed with an accelerated hammer with a mass of 7 tons and a theoretical energy of 75 kNm. The work started in August 1997. After a couple of weeks it was obvious that the pile driving equipment wasn't efficient enough with respect to the time schedule. It was common with pile-stop after 20 m quite hard driving without reaching the rock. After some days without driving it was possible to drive the pile further. So called "false refusal" was a matter of fact.

To increase the capacity of the pile driving it was necessary to take alternative measures to decrease the amount of blows for the installation with the originally selected equipment or change the equipment to a more efficient one. However the allowed noise level was reached (and in some cases exceeded) with the initially selected pile driving equipment. To avoid exceeding the stated noise level the first alternative was to reduce the amount of blows during the installation through drilling beside the pile during the driving. High water pressures had been observed during the pile driving. The drilling reduced the pore pressure and had a good effect on the capacity of the pile driving, but not good enough. Hence it was decided to add an equipment with a more efficient hammer to make the final driving of the piles. That implied that it was also necessary to take additional measures to increase the noise damping. These were performed in two ways. The first was a tube of concrete with a length of 5 m placed around the pile and the hammer during the final pile driving. The second way was a wall of normal transport containers with a height of about 10 m placed on three sides of the foundation area. Together these measures were efficient to reduce the noise level so it was possible to perform the piled foundation without exceeding the stated maximum noise level in any apparent way.

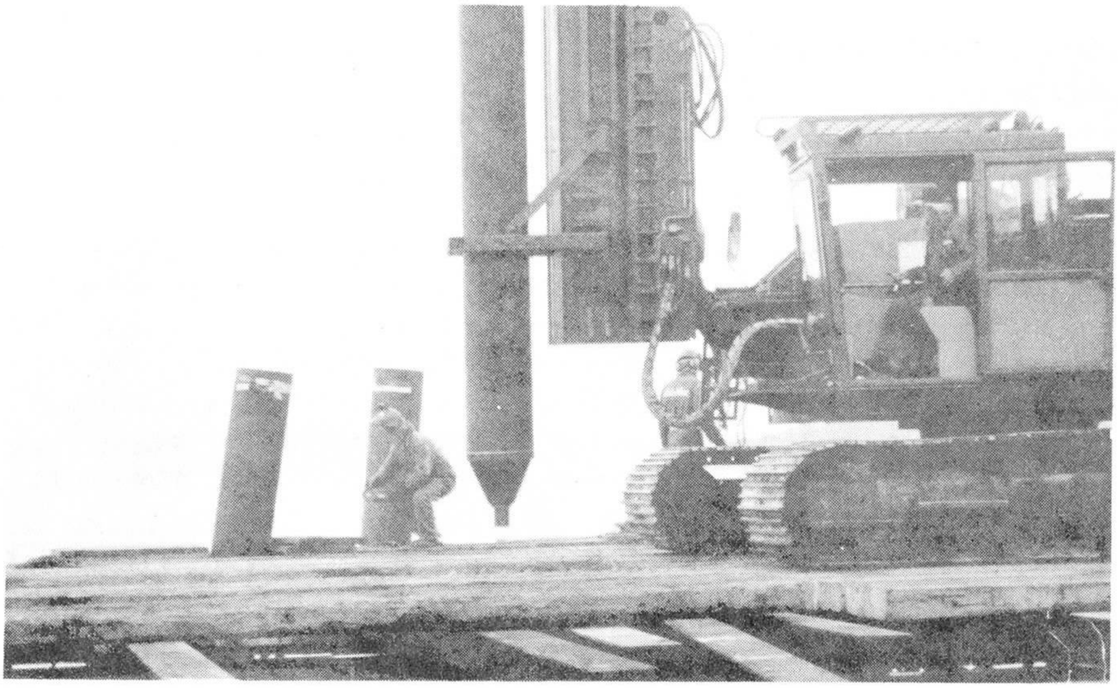

Figure 3. Pile driving equipment used for foundation at support N6 and N7.

The northern approach bridge is founded with footings on solid rock, in soil and on piles driven to rock. The additional geotechnical investigations for the piled foundations (support N5, N6 and N7) indicated that the rock surface locally has steeper slopes than originally assumed. Hence some of the pile toes were redesigned with a steel dowel as mentioned above. The foundation works were performed in principal in accordance to the original design. Compare photo in figure 3 showing the equipment for pile driving of the steel pipe piles at support N6 and N7.