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Höga Kusten Bridge: Main Cable Anchorages and Pylon Foundations

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Lars Pettersson, born 1959, received his civil eng. degree 1984. He was until 1997 Head of Bridge Dept at Kjessler & Mannerstrale AB (KM). KM was appointed by the Swedish National Road Administration as main consultants for the detailed design of the Höga Kusten Bridge.

Summary

The newly finished Höga Kusten Bridge (opened to traffic on the 1st of December 1997) in the northern part of Sweden is with its 1210 m main span one of the largest suspension bridges in the world. The bridge carries the road E4 over the mouth of the river Ångermanälven which is more than 1 km wide and 90 m deep at the bridge site. Ground rock conditions at the bridge site has made it possible to use rock as counter weights for the large pulling forces from the main cables. Also, rock is used to found the towers in excavations 13 - 18 m below river surface. In the following, a presentation of the various design aspects for the main cable anchorages and the tower foundations along with some of the construction methods chosen are presented.

1 Introduction

The Höga Kusten Bridge in the northern part of Sweden some 500 km north of Stockholm is designed as a suspension bridge with a main span of 1210 m and an overall length of over 1800 m. The bridge is designed to carry a dual-lane highway and has a minimum clearance under the main span of 40 m. The overall width of the aerodynamically formed bridge girder is 22 m as shown in Fig. 2.

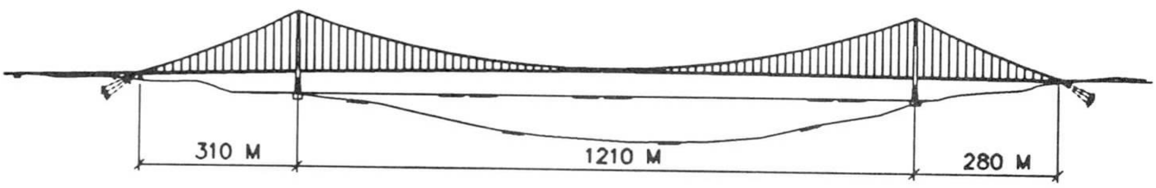

Fig. 1. Elevation of the bridge. The total length exceeds 1800 m with the three suspended spans being 310 m, 1210 m and 280 m respectively.

Water depth at the bridge site being 90 m made a suspension bridge concept the only feasible bridge alternative. Rock ground conditions at the bridge site has made it possible to both found the towers on rock and to anchor back the very large pulling forces from the main cables using rock as counter weights.

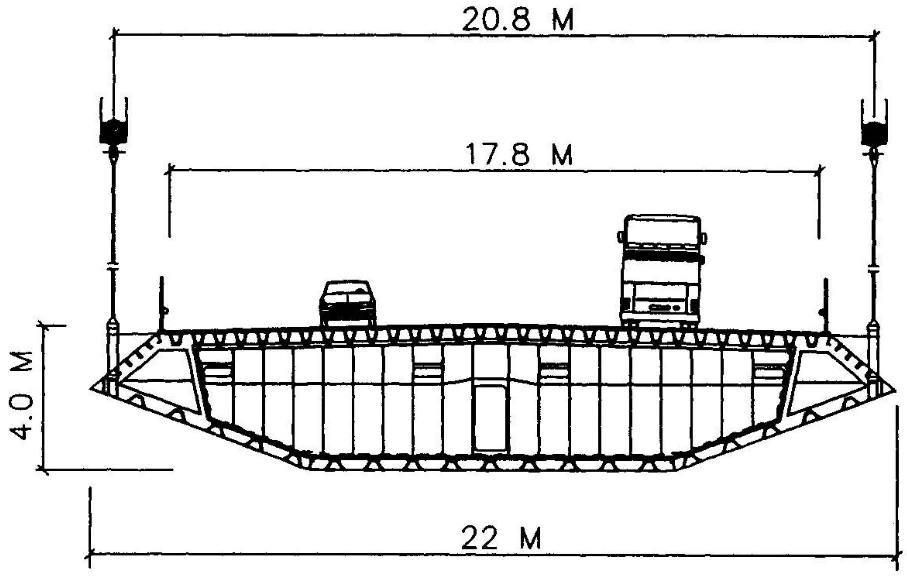

Fig. 2. Cross section of bridge girder. Overall width 22 m, effective width 17.8 m, height 4.0 m and distance between main cables 20.8 m.

The Swedish National Road Administration (SNRA) appointed the Swedish company Kjessler & Mannerstråle AB, (KM) as main consultants for the design and detailed design of the bridge. In the all-nordic design team the following companies were represented: Ahlgren Edblom Architects AB, Sweden, COWI AS, Denmark, The Geotechnical Institute of Norway, Danish Maritime Institute, Denmark, Haug and Blom-Bakke AS and SINTEF, both from Norway and VTT Finland.

Chief Engineer for the total Höga Kusten Project is Karl-Erik Ekesund for the Swedish National Road Administration. Chief Engineer for the Design Team is Gerner Rörsö Jörgensen for KM with Lars Pettersson as deputy Chief Engineer.

The Höga Kusten Bridge was built by a joint venture called Scandinavian Bridge Joint Venture (SBJV) consisting of Skanska AB (Sweden), Monberg og Thorsen AS (Denmark) and Alfred Andersen AS (Norway). As subcontractor for the fabrication the 1800 m long steel superstructure SBJV choose the Finnish company Finnyards OY.

2 Articulation of the bridge

The Höga Kusten Bridge is designed according to Swedish design codes and standards although codes for aerodynamic wind design had to be developed as part of the design of the bridge.

The articulation of the bridge is shown in Fig. 3. The two aerial spun main cables are anchored in rock on each side of the river. The superstructure is continuos between the two abutments. The length of the superstructure is therefore 1800 m.

Temperature variations and main cable deformations caused by live load leads to very large longitudinal movements at the abutments. These longitudinal movements are therefore blocked by large hydraulic dampers at each end of the superstructure, compare Fig. 4.

The limitation of longitudinal movements will result in restraining forces, however, these are absorbed by the abutments.

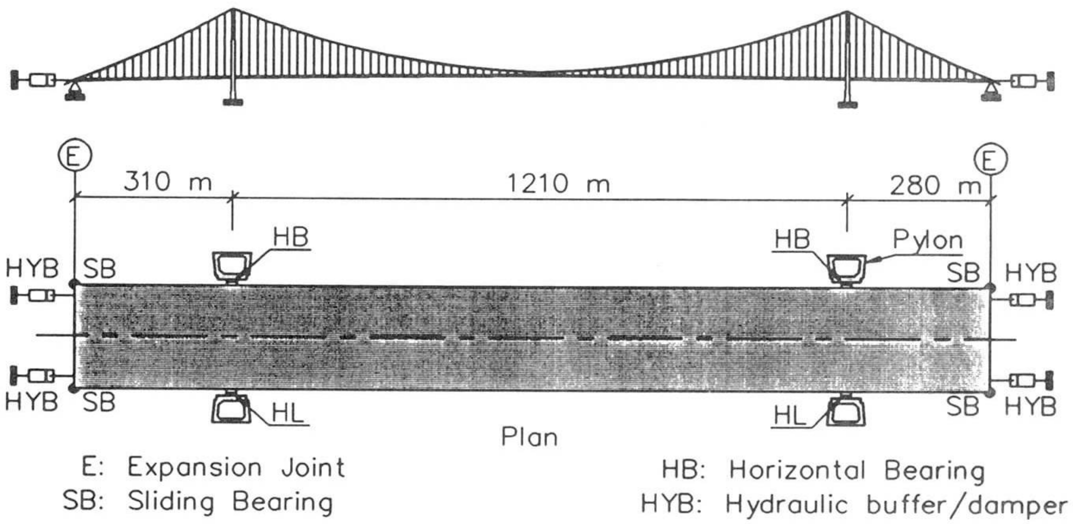

Fig. 3. Articulation of the bridge

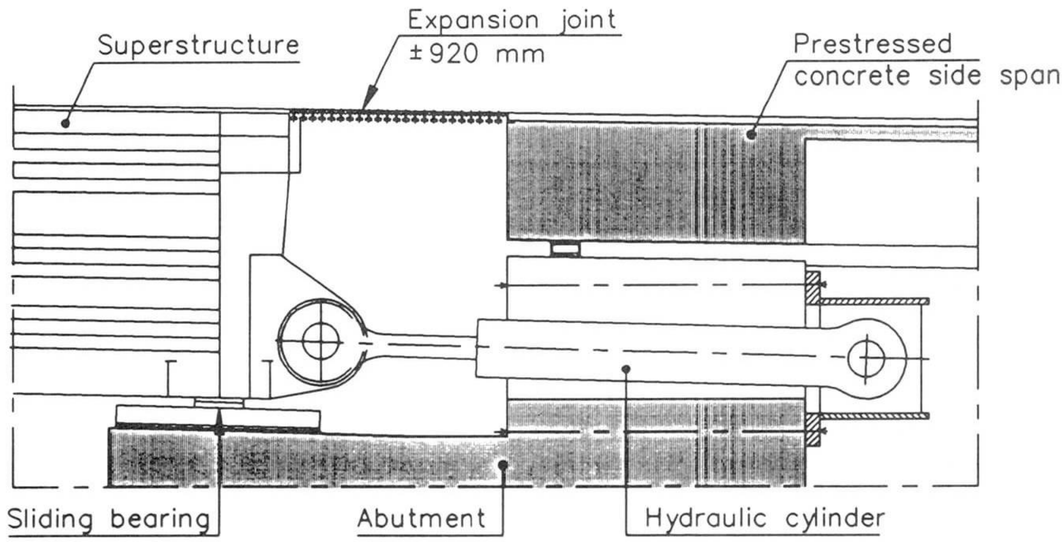

Fig. 4. Hydraulic dampers at bridge abutments reducing longitudinal movements to ±0.85 m.

3 Main cable anchorages and abutments

The design of the Höga Kusten Bridge with its two side spans over land has made an integrated and compact design of the abutments and main cable anchorages possible. This integrated design has lead to comparatively small abutments.

In the splay chamber, the main cable is spread out and deflected over a steel splay saddle as shown in Fig. 5. The splay chamber is equipped with a dehumidification system in order to minimise maintenance requirements. The main cable strands are anchored to steel bars threaded in anchor plates cast into a concrete slab.

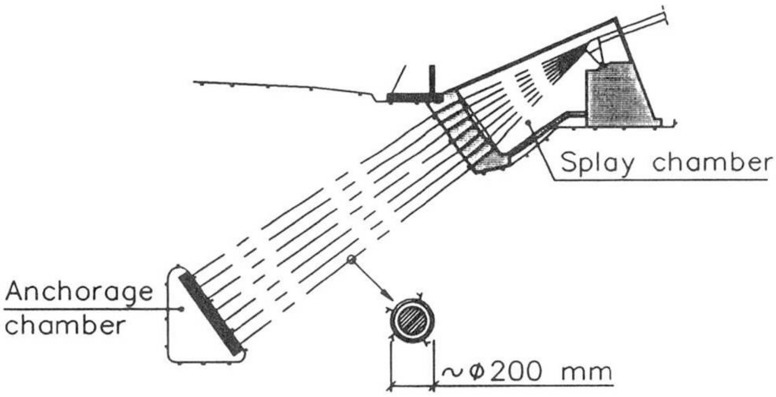

Fig. 5. Main cable anchorage.

The splay saddles rests on massive, 450 m^3 concrete block structures which form part of the forward part of the abutment. These concrete blocks are founded directly on rock reducing the necessary foundation area to a minimum. The force from the splay saddle is used to partly balance the large horizontal forces (18 MN, ultimate limit state) from the hydraulic buffers.

Between the splay chamber and the anchorage chamber, for each main cable, 39 prestressing strands placed in approximately 38 m rock drilled holes with 200 mm diameter. The drilling equipment was specially developed for this purpose.

The 39 strands were prestressed against two large concrete slabs, one in the splay chamber and one in the anchorage chamber. These concrete slabs with concrete volumes up to 400 m^3 were cast directly onto rock resulting in relatively large restraining forces during hardening of the concrete. Thus, at the concreting process cooling efforts by water and air minimised the risk for concrete cracking due to temperature and restraining effects.

The prestressing strands are protected from corrosion by PEH-tubes. Grouting with cement mortar were carried out both between the PEH-tubes and the rock (before installation of the prestressing strands) as well as between prestressing strands and PEH-tubes following prestressing operations. The grouting between rock and PEH-tubes is critical. Therefore the PEH-tubes were filled with water to outbalance the pressure from the grouting mortar.
The prestressing tendons (VSL-type) consisting of 32 each 0.6 inch strands giving each tendon a breaking load of 8.5 MN. Totally the tendons for each main cables have a ultimate load capacity of approximately 330 MN. The partial coefficient of 1.75 for the forces in the prestressing tendons is used in the ultimate limit state.

The front part of the abutments has been used for many purposes, the most important being:

- base for the splay saddles
- support for the suspended side spans
- support for the hydraulic cylinders
- support for the prestressed 23 m side spans bridging over the splay chambers
- providing space for telecommunication and electrical installations

Dominating forces acting on the abutments are splay saddle reactions and reactions from the hydraulic cylinders. Reactions from the hydraulic cylinders being relatively small in serviceability limit state increase in ultimate limit state to approximately 18 MN on each cylinder. To balance this very large force both the vertical reaction from the splay saddle and the weight of the concrete side spans are used.

4 Pylons

The pylons are given a very special architectural treatment, compare Fig. 6. From aesthetical reasons both pylons are placed in the river close to the shore line. The total height of the pylons are 196 m of which approximately 179 extends over water surface. With over 12 m high steel and glass spires places on the pylon tops the total height of the pylons is over 200 m. The pylons are designed as plane frame reinforced concrete structures with transversely inclined legs with two transverse prestressed beams. The pylons are founded on solid rock on full (solid) cross section foundations cast in dryness. To reach solid rock for the southern pylon excavation of about 5 m bad rock was necessary before foundation works were carried out. On the northern pylon foundation could be carried out directly on solid rock at a water depth of about 17 m. The pylons are designed to withstand ship-collision impact from vessels up to 40,000 tons displacement.

The pylon concrete was chosen with relatively low strength in compression (grade K40 according to Swedish standards). The reason being the large dimensions and the wish from the designers to keep heat release during the concrete hardening process as low as possible.

The water cement ratio has been varied in the different parts of the pylons. Especially in the very large solid block foundations a low cement content was important. In the inner parts of the foundations a water cement ratio was therefore chosen to 0.52 while in the splash zone of the pylon legs a water cement ratio of 0.40 was chosen. Concrete cover, both for foundations as well as pylon legs, is 70 mm.

For the pylons approximately 32000 m^3 of concrete, 3000 tons of reinforcement and 80 tons of prestressing tendons are used.

The pylons where built by climbing formwork, the climbing steps being approximately 4 m.

The pylons are both founded on rock. The foundation levels are between 13 and 18 m below river surface. In spite of the large water depth the foundations are cast in dryness, compare Fig. 7. Foundation work has been carried out inside large sheet pile walls. The sheet piles where made tight to the rock by under water cast concrete beams at the inside of the sheet pile. These beams where in turn supplemented by grouted vertical cut-off walls directly under the sheet pile walls.

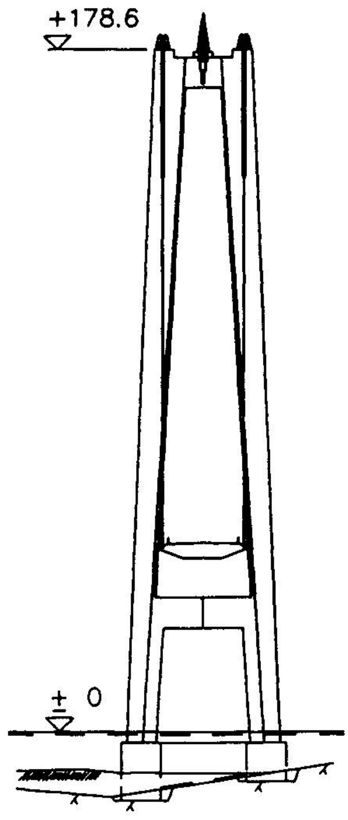

Fig. 6. Pylon elevation.

The foundations have been made relatively long in the direction of the bridge axis to ensure stability without rock anchors even in the critical free standing condition. In spite this, due to the high quality of the rock the length of the foundations could be limited to 15 m, the width being 9.5 m.

The four foundations where all cast without construction joints leading to approximately 2000 m^3 castings. The time used for casting one of the foundations were approximately 36 hours.

To control the large heat release the concrete was cooled with river water running in steel pipes mounted on the horizontal reinforcement. The distance between the pipes was approximately 800 mm horizontally and 1000 mm vertically.

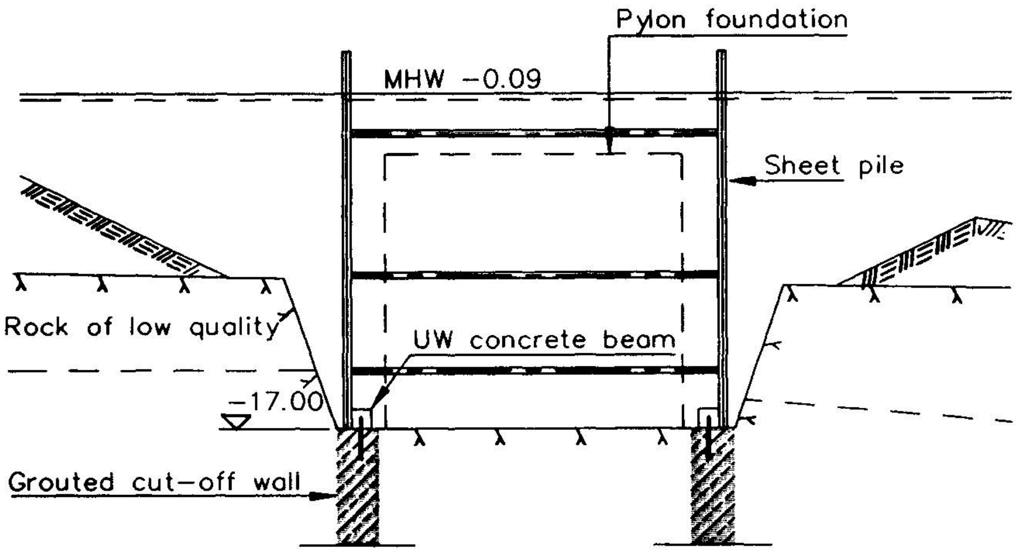

Fig. 7. Pylon foundations. Temporary sheet piling shown.

The total vertical reaction on the rock foundation is approximately 500 MN from dead load only resulting in a ground pressure of 2 MPa. In the ultimate limit state the ground pressure was allowed to increase to 3.5 MPa. In the accidental limit state combinations of vertical and shear stress were checked against rock failure envelopes.

5 Concluding remarks

The Höga Kusten Bridge is with its 1210 m main span the largest bridge in Sweden. This complicated bridge project has been successfully completed at the end of November 1997. The high quality rock at the bridge site has been used to minimise structure dimensions, especially the main cable anchorages and pylon foundations.

6 References

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