Sunningesund cable-stayed bridge

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Summary

The Sunningesund bridge, today named the Uddevallabridge from the town Uddevalla located on the Swedish west coast, is part of the motorway E6 between Gothenburg and Oslo. Construction of the bridge started in mid 1997 and is scheduled completion during summer 2000. This paper gives a description of the bridge, the early design considerations, the wind investigations and the construction methods.

1 Introduction

The Uddevalla bridge consists of three parts, the south approach bridge, the cable-stayed main bridge crossing the navigation channel to Uddevalla and the north approach bridge. The total length is 1712 m. This section of the E6 passes through a very beautiful province of Sweden, thus the motorway is constructed with considerable emphasis concerning the surroundings with all sections of the bridge being detailed carefully and given high quality with regard to the aestethic. A design-built contract was awarded to Skanska and the contract was signed with the Swedish Road and Bridge Administration in the early 1997. The detailed design is carried out for the contractor Skanska by Skanska Teknik AB, a subsidiary of Skanska AB and Johs Holt A.S in Norway.

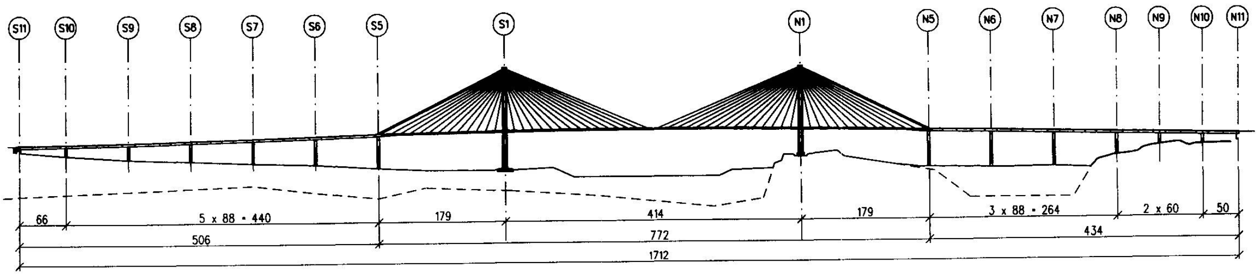


Figure 1

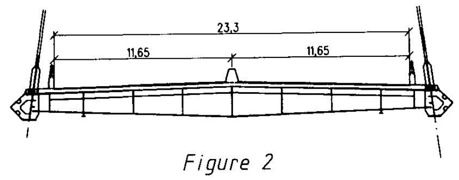
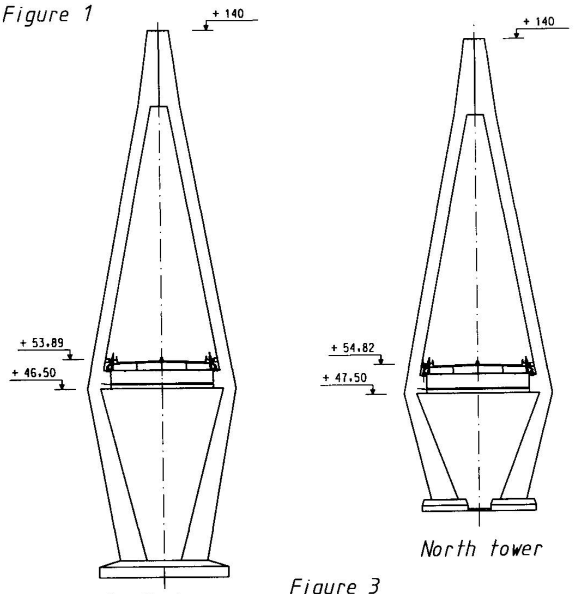


Figure 2



South tower

North tower

Figure 3

2 Description of the Bridge

2.1 Overall configuration

The bridge is a high-level bridge of total length 1712 m carrying 4 traffic lanes, ***figure 1***. The central cable-stayed section provides a navigation clearance 190 m wide and 52 m high over the Sunninge Sund. The approach bridges to either side of the cable-stayed section at the centre, have a total length of 506 m at the south side and 434 m at the north side. The spans increase from 50 m at the north abutment to typical 88 m towards the centre. The cross-section of the superstructure is constructed using two separate steel box girders with concrete deck cast in situ. The design is conventional and not further described in this paper. The central cable-stayed bridge is made up of a 414 m main span and two 179 m spans either side. The cables supporting the bridge are arranged in slightly inclined cable planes nearly parallel to the tower legs. They are anchored at equidistant intervals along the bridge deck of 13,32 m except for the outer 3 back stays which are concentrated at the anchor piers N5 and S5, ***figure 1.***
The entire structure is continuous with expansion joints only at the abutments. Continuity between the approach bridges and the cable-stayed bridge is provided by a heavy concrete transition structure. The six piers at axes N5-N7 and S5-S7 are hinged to the bridge superstructure and contributes to the stability of the bridge in the longitudinal direction. All other piers are equipped with sliding bearings.

2.2 Bridge superstructure

The bridge cross-section in the stayed spans, ***figure 2***, is a composite structure of an open steel grid and prefabricated concrete slab elements. The wind nose, connected to the outer longitudinal I-beam, is a load bearing thin walled shell structure. The stay cables are directly connected to the web of the 1,7 m high longitudinal girders.
The slab elements are spanning longitudinally and are connected by loop reinforcement in the cast in place joints. The thickness of the concrete elements is 240 mm and longitudinal reinforcement of 20 mm bars at spacing 160 mm is generally provided to achieve satisfactory strength and limitation of crack widths to 0,20 mm.
The bridge-cross section accommodates 6 traffic lanes.

2.3 Towers

The towers are made of concrete grade K55 according to the Swedish Standard BBK 94. They are diamond shaped and rise to elevation 140, **figure 3**. At the tower top the stay cables are anchored inside steel boxes fixed to the concrete by shear studs. The tie-beam between the tower legs is fully post-tensioned for the outward thrust from the tower legs.
According to the project specifications no cracking of the tower is allowed during the construction period. This criterion imposes strict limitations on the erection procedure for the bridge superstructure and temporary struts between the tower legs are required. Also temporary supports of the superstructure are necessary.

2.4 Stay cables

The stay cables consists of 22 to 77 strands (15,7 mm), individually galvanised, waxed and sheathed. The bundle of strands is covered by an external HDPE pipe.

The void between the strands and the external pipe is maintained empty. The stay cables and the anchorage system is delivered and installed by VSL.
The structure has been designed to allow for exchange of any stay cable for a situation with a reduction in live loads to three opposite lanes. In addition any stay cable can be accidentally removed under full traffic load without structural instability or inelastic deformations.
Cable vibrations have been a problem on several cable-stayed bridges. To our knowledge, no well documented theory exists for evaluating the risk for such vibrations. Thus the following precautions have been taken:
- The external HDPE pipes have ribs to prevent so called "rain-wind vibrations".
- The longest cables will be equipped with dampers, probably hydraulic dampers outside the anchorage. The damping system is currently being evaluated.
- The cable system shall allow for future installation of transverse stiffening ropes if deemed necessary.

3 Design Development

3.1 Conceptual Design

Due to strict limitations in the project specifications the main span could at an early stage be fixed to 400-420 m. The remaining but rather challenging task was to select suitable shapes and dimensions of the bridge cross-section and the towers.
Three alternative cross-sections, all composite, were evaluated:

a) An orthotropic steel box girder with concrete deck. Two cable planes.
b) As a), but with a single, central cable plane
c) An open steelgrid with bridge deck cast in place or made up of pre-fabricated slab elements

Alternative c) was found to be the most economical and also aestethically acceptable. The structural adequacy of this type of cross-section has been clearly demonstrated by several long span bridges completed during the last decade. Alternative c) was thus selected for the final design.
Two tower shapes were investigated: Diamond and H-shapes. The lower cost of the H-tower legs was to some extent balanced by higher foundation cost due to separate footings for the H-tower. Finally, the diamond shape was found to be the most suitable, combining aspects of economy, aestethics and structural behaviour.

3.2 Wind effect investigations

The wind climate at the bridge site is not particularly severe. The 10-minutes average wind speed at the bridge deck level is 32, 8 m/s and the turbulence intensity 14,7%. Above values refer to a return period of 100 years, relevant for the completed bridge. For the construction phase, a return period of 10 years applies.
Wind tunnel tests on sectional models were performed to determine the aerodynamic stability, the sensibility to vortex shedding and the aerodynamic force coefficients. The tests comprised three model configurations:

1. The completed bridge without traffic
2. The completed bridge with traffic
3. Construction stage

The sectional model was tested both in low turbulent and high turbulent flow. The test results confirmed that the stability criterion of 53 m/s was achieved with an ample margin.
According to the project specification for traffic comfort, the RMS of the vertical acceleration should be less than 0,3 m/s^2 for frequencies lower than 1Hz at a 10-minute wind speed of 25 m/s at bridge deck level. Also this criterion was fulfilled.
The wind tunnel investigations were carried out by the Norwegian University of Science and Technology, Trondheim in co-operation with Svend Ole Hansen ApS, Copenhagen, **(I).**
The results of the wind tunnel testing have been used as basis for a series of buffeting response analyses. These analyses cover the completed bridge with and without traffic and critical stages during construction. The buffeting analyses have been carried out with the SVING program developed by Hans Björge, **(II)**

3.3 Static analysis and design

A step by step analysis including all structural systems during the various erection stages until completion of the bridge has been performed. Time dependent strain from creep and shrinkage is included, also amplification of bending moments due to second order effects. Non-linear influences from cable sag showed to be limited. The stay-cables have therefore been modelled as linear elements with an effective modulus of elasticity. The analysis has been performed with the RM-spaceframe programme. **(III)**
ULS-criteria govern in most cases the design of structural elements. An exception is the stay cables where the SLS-criteria is governing.

4 Foundation Structures

The geological presumptions and geotechnical conditions at the bridge site vary considerably, typical for the Swedish west coast. All types of foundations have been used for the bridge. The south approaches and the south pylon are placed on or close to an edge from the inland ice with layers of moraine, gravel and sand formed during a period of 200 years, 12000 years ago. In the north the rock level is varying from 100 m below sea level to 35 m above.
The south abutment S11 and the three next piers S10-S8 are founded on well natural compacted material from the inland ice. The piers S7-S5 are founded on driven precast concrete piles having lengths varying between 14 m to 25 m, 350 mm square and bearing capacity of 1600 kN. The loads are carried combined by surface friction and by pile tip. The south pylon S1 is placed in the sea close to the shore and founded on driven sheet piles to the rock with a diameter of 700 mm. After having checked the straightness the piles are filled with concrete cast in dry and partly reinforced. With a bearing capacity of 4700 kN the loads are carried by a composite structure, steeltube-concrete, taking into account the corrosion in the surface of the steel sheet, the lengths are 25-28 m.
The north pylon N1 is founded on a rock base 20 m above sea level.
The anchor pier N5 is founded on piles of drilled steel cores with diameter 210 mm and 150 mm and length of 6 m to 15 m due to the excessive big slope of the rock. Bearing capacities are 3600 kN respectively 2500 kN. The next two piers N6, N7 are founded on driven sheet piles to the rock, diameter 500 mm and maximum length 30 m to 80 m. Concrete fill and composite structure similar to pylon S1 and a bearing capacity of 2400 kN. The rest of the piers N8-N10 and abutment N11 are founded on rock.

5 Construction

Towers and piers are built by climbing formwork in sections of approx. 4 metres, and reinforced to a large extent by prefabricated nets or cages lifted into place. The superstructure of the main bridge will be erected by free cantilevering from the towers outwards. Stability of the bridge system during erection is ensured by 3 auxiliary towers, supporting the bridge superstructure. Pre-assembled steel grid sections of 13,32 m length will be lifted up and welded to the previous section. The cables are then installed and stressed, the precast slabs are positioned and the joints between them casted. After final tensioning of the stays the next section will follow.
The steel box girders of the approach bridges will be welded to continuous girders behind the abutments and launched to right position. After that the concrete slab is reinforced and casted in situ on a travelling scaffolding.

6 Concluding remarks

The construction work is now well under way with the exception of the tower S1 where the foundation work is almost completed. Launching of the steel box girders of the approaches will commence in March 1998. Erection of the steel superstructure in the main span is planned to commence in August this year. The bridge is scheduled for completion during summer 2000.

ACKNOWLEDGEMENTS

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Contractor:	Skanska Civil Engineering AB, Bridge Department
Stay cables:	VSL International Ltd
Structural design:	Skanska Teknik AB in co-operation with Johs. Holt A.S.

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(III) TDV: RM-Spaceframe Users Manual, rev. 5.80-09/96