CONSTRUCTION OF THE HARDANGER BRIDGE

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BIOGRAPHY

Henning Schultz is a Project Director in MT Højgaard A/S; one of the leading construction and civil engineering companies in the Nordic region of Europe.

Henning holds a MSc in Civil Engineering from the Technical University of Denmark and a BSc in Finance from Copenhagen Business School

Henning has worked for several years within the world of construction. He began his career in Monberg & Thorsen and has since been involved in the construction of several large bridge projects such as the Øresund Bridge, Höga Kusten suspension bridge in Sweden, The Great Belt Link in Denmark, The Askøy Suspension bridge in Norway, the Millennium Bridge in London, England and Refit of suspenders for the Forth Road Bridge in Scotland.

Henning's experience in large cable supported bridges involves managing international tenders for large steel bridge projects.

Currently Henning is also the Chairman of IABSE Denmark.

Michael S. Christensen is a Design Manager in MT Højgaard A/S.

Michael graduated with a MSc in Civil Engineering from the Technical University of Denmark in 1982.

Michael began his career in 1983 working for Monberg & Thorsen and later MT Højgaard. Michael has an extensive history in installation engineering and design management on various bridge projects e.g. The Farø bridges in Denmark, Pont de Normandie in France, Höga Kusten suspension bridge in Sweden, the Millennium Bridge in London, England and recently the Hardanger Bridge in Norway.

Michael also has experience in offshore wind farm projects.

SUMMARY

In 2009 MT Højgaard A/S was awarded the contract for the steel and installation works on the main cables and the box girders on the Hardanger Bridge from the client; The Norwegian Public Roads Administration in Norway. The bridge opened for public traffic August 17, 2013

This paper explains the main activities in constructing the Hardanger Bridge, the world's 8^{th} longest suspension bridge with a span of 1310 meters across the Hardanger Fjord.

The description takes the reader through the extensive construction engineering beginning with the spinning process of the main cables, the many temporary structures, platforms and equipment. The fabrication of the box girders in China, the direct shipment of the entire bridge in one shipload from the fabricator in China to the bridge site in Norway, as well as the direct lift of the box girders from the ship moored below the main cables by a purpose designed installation crane on the cables is also described.

Furthermore the completion of the bridge by welding all box girder joints, surface treatment of box girders and wrapping the main cables and preparation for dehumidification of both box girders and main cables etc. is described.

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Abstract

The Hardanger Bridge in Norway is a suspension bridge with a main span of 1310 metres across one of Norway’s deep fjords – the Hardanger Fjord.

At the bridge location the water depth is about 550 metres thus the pylons are founded directly on the steep rock on each side of the fjord.

The bridge deck carries two lanes of traffic and a lane for pedestrians and bicycles. The average daily traffic was expected to be approximately 2400 vehicles per day. The bridge deck is designed as a closed box with a depth of 3.25 metres and a total width of only 18.5 metres making the bridge the most slender large suspension bridge in the world.

In order to gain sufficient aerodynamic stability the girder is provided with wind vanes.

The main cables each consisting of 10032 nos. of 5.36 mm wires are established by traditional air spinning.

MT Højgaard situated in Copenhagen, Denmark, was the contractor for the steel superstructure. The box girder sections were fabricated in Shanghai, China and all of the girder sections were delivered in one shipment only. A special feature was the lifting and installation of the box girder sections directly from the transportation vessel. During installation of the main cables a special stiffening system for the cat-walk was established in order to gain more up-time for the tramway system during high winds.

The contract was awarded in 2009 and installation on site started in the summer of 2011 with completion of the bridge and opening for traffic on August 17, 2013.

The presentation will go through the different phases of construction of the steel superstructure. This includes the prefabrication of box girder sections, fabrication of cable wire and other components, the installation of cables and main girder and focuses on the construction engineering needed for installation for a large steel structure.

The bridge, designed by Norway’s Forum Architects, is an iconic new landmark with its two 200 metre high concrete towers and a steel construction that seems to ‘hover’ in the air between the mountains on either side of the fjord.

1. Introduction

The journey between the Norwegian cities of Oslo and Bergen has become significantly quicker following the replacement of the old ferry connection across the Hardanger Fjord with a new suspension bridge in August 2013.

The Hardanger Bridge is the longest suspension bridge in Norway. It has two traffic lanes and a combined bicycle lane and footpath. With a total length of 1,380 metres and a main span of 1,310 metres, the bridge is 30 metres longer than Golden Gate Bridge, but shorter than the Great Belt Bridge, which has a span of 1,624 metres.

During the construction period, MT Højgaard assembled around 15,000 tons of steel. The two suspension cables alone weigh 6,400 tons, and were installed using a wheeled cable track which rolled back and forth across the fjord at a height of 200 metres. Each cable has a diameter of 60 cm, and contains 10,032 wires.

The traffic lanes are supported by 23 box girder segments each weighing approximately 400 tons. They were shipped in under the bridge and hoisted up by means of a specially constructed crane, after which they were welded together.

The concrete work and civil works were carried out by Norwegian contractors, while MT Højgaard executed the steel and assembly work.

The bridge, designed by Norway's Forum Architects, is an iconic new landmark with its two 200 metre high concrete towers and a steel construction that seems to 'hover' in the air between the mountains on either side of the fjord. See Figure 1.

The bridge will service the people of Norway for many years.

Figure 1 – View of the Hardanger Bridge.

2. Time Schedule

The time schedule for the steel and erection works was as follows:

2009: Planning and contracts for major supplies.

2010: Fabrication of equipment

Construction site facilities

2011: Construction of the temporary working platforms, “Cat-walk”

Spinning of the main cables

2012: Installation of cable clamps and hangers

Assembly of Installation cranes

Transport of the box girders from China

Installation of the box girder elements and welding together

Cable wrapping with wire and tape

2013: Cable sealing and dehumidification

Bearings, expansion joints, platforms and railings

Finalizing and opening for traffic August 17, 2013

3. Construction Engineering

The construction of a large span suspension bridge requires many temporary constructions and equipment, most of them are purpose designed and will be scrapped upon completion of the bridge. Although the temporary constructions and equipment had a very short life span compared to the bridge (which is designed to last for a minimum of 100 years) the design efforts are typically twice the design efforts for the permanent bridge structure.

The main temporary constructions were:

- Working platforms at the top of the pylons.
- Tower cranes installed on both pylon tops, to have fast transportation of material to working platforms and catwalk.
- The cat-walk, which enables the construction of the main cables.
- Storm rope system that stabilizes the catwalk until the main cables are constructed.
- Spinning equipment, complete with wire reel stands, buffer tower, tramway with drive unit and control systems, spinning wheels and cable formers etc.
- Sea fastening of the box girders onboard the transport vessel.
- Installation of crane and lifting equipment.
- Platforms for access below the box girders for welding and surface treatment.

4. Construction Methods

For a large suspension bridge like the Hardanger Bridge it is essential to have full control over deflections and stability during the installation phases.

As an important part of the planning process Method Statements were developed for all operations in order to secure a safe and efficient construction process.

Furthermore Quality Control Plans were established to plan an effective quality control process and documentation system.

The method of providing horizontal equilibrium at the pylon tops had on the Hardanger Bridge was chosen to be the pylon pullback method. The pylons were pulled back 466 mm before the spinning started. The main cables are spun at the pylon position, but just before the box girder installations started and during the installation the pylon pullback cables were slackened in steps, and upon completion the pullback cables were dismantled. See Figure 2.

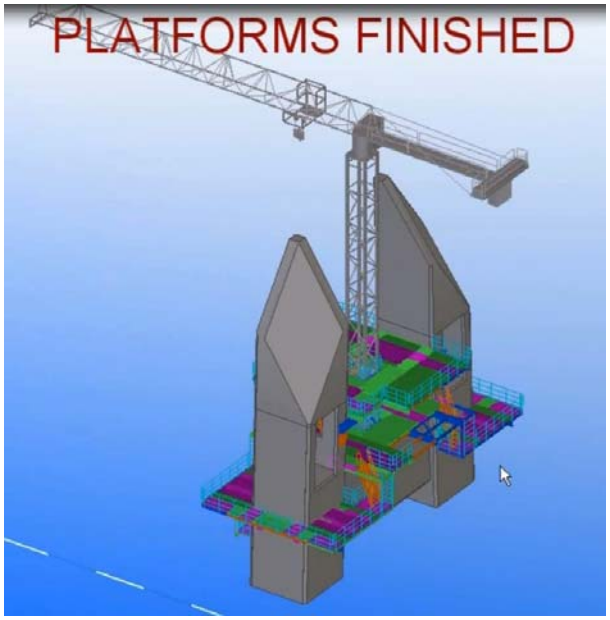

Figure 2 – From 3D model for planning tower top platform installation.

5. Design and Assembly of the Cat-Walk

The Cat-Walk was designed by MT Højgaards own Design and Engineering department.

The purpose of the catwalk was to have a temporary working platform to mount the main cables, cable clamps, hangers and dehumidification wrapping etc.

There were two catwalks made of 10 floor ropes and 2 hand ropes. The catwalk floor was made by steel nets with mounted wooden steps. Each catwalk was reinforced by a frame to support the 12 ropes.

A storm rope system was mounted below the catwalk in order to stabilize it during times of extreme wind conditions in the fjord.

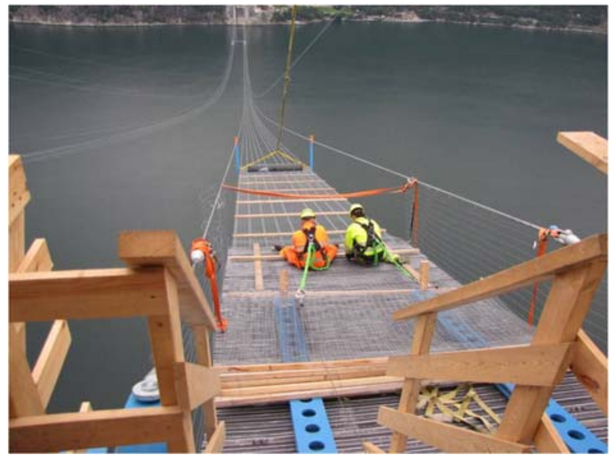

Figure 3 – Catwalk netting under construction

6. Spinning of main cables

The main cables were constructed using the aerial spinning method. Each main cable consists of 19 strands each with 528 wires i.e. 10032 wires in total. Each wire is 5,36 mm in diameter of galvanized high grade steel with strength of 1570 MPa and the total amount of wire is approximately the circumference of the earth.

The wires were wound on reels at the wire manufactures workshop and transported to the bridge site by ship in standard 40' containers.

It is a challenging process to spin the wires at only 5.36 mm in diameter and control them in the gusty wind high above the fjord, and upon completion of each strand to adjust the cable strands into the correct sag in each span.

The strands in one main cable were spun on one catwalk, while squeezing and adjustment of the previously spun strands took place on the opposite catwalk. Upon completion of one set of strands, the spinning operations swapped between the catwalks and spinning of the next pair of strands could start.

The spinning process is called controlled tension, as the wires are partly supported on the cable formers on the catwalk and partly free hanging in balance with a controlled tension supplied by the dead weight from the floating sheaves in the buffer tower at the wire reel racks.

On each cat-walk two spinning wheels travelled on the tramway system.

Figure 4 – Spinning wheel travelling from the pylon with 4 loops of wire.

7. Box girder fabrication

The box girders were fabricated in China and shipped to site in Norway. The bridge cross-section has a 2 lane carriage way together with a pedestrian and bicycle path. The width of the box girder is 18,5 metres and the depth is 3,25 metres, and the box girders have transverse bulkheads at 4 m spacing.

The sections were 60 metres long and all 23 box girders were delivered to the site in one ship load. The box girders were lifted off the ship by a purpose designed installation crane developed and designed by MT Højgaard.

Figure 5 – Fabricated box girders ready for load-out.

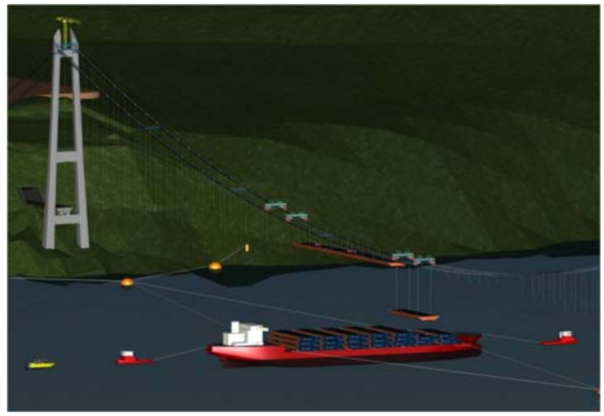

Figure 6 – Installation of box girders with direct lift from the transport vessel.

8. Welding of the sections

When all 23 box girder elements had been lifted and installed on the hangers, the welding could start at the centre of the main span where two welding teams each welding one joint at a time while worked their way towards the pylons.

Figure 7 – Welding of box girder joint inside tent.

Each box girder was fabricated with the same length on the deck and at bottom level i.e. with rectangular ends at 90 degrees, but due to the curved longitudinal bridge profile with a radius of 20.000 metres, the box girders was forced to meet at the welding joint by temporarily lowering the pair of hangers at either side of the welding joint. By using this method the girder ends were given a small rotation, yet enough to have a welding joint free of internal forces and to build in the requested moment distribution in the girder.

All joints between box girders had been preassembled at the fabrication yard with trial assembly brackets, and that geometry was re-established on site within a weather window to have moderate external forces on the brackets during the welding process. The skin was welded first and NDT was made, and subsequent welding of patch pieces for the 44nos. of U-ribs was done. See Figure 8 and 9.

Figure 8 – Box joint at start of welding process

Figure 9 – Box girder sections at fabrication yard with assembly brackets at the upper deck edge.

Surface treatments of the exterior surface at the welding joint areas were performed from access platforms. Surface treatments consisted of Thermal Sprayed Zink (TSZ), TSZ sealer, intermediate epoxy, topcoat of polyetheran and a minimum layer of thickness consisting of 300 μm DFT. Hydraulic dampers, expansion joints, dehumidification systems and bridge railings etc. were then installed.

Road paving works were carried out as the completing operations before the bridge opening in August 2013 took place.

9. Cable Wrapping & Dehumidification System

Upon completion of the spinning process the compacting, erection of cable clamps and hangers will take place before the box girders arrive. The bridge has 65 sets of hangers between 2,0 metres and 127.5 metres long. The cables will be wrapped with galvanized 3.5 mm diameter steel wire, and on top of that wrapped with polyethylene tape.

The Hardanger Bridge is one of the first bridges to have dehumidification system of the main cables installed during the construction, and a detailed test programme has been executed together with the client, the designers, and the subcontractor for wrapping and sealing works.

Monberg & Thorsen, which later merged into MT Højgaard, introduced dehumidification systems to the bridge building industry in the 1960's on The Little Belt bridge, and the dehumidification technique have become industry standard for corrosion protection for the interior of bridge boxgirders ever since, and now this technique is also being used to prolong the lifetime of the main cables.

Figure 10 – Cable wrapping in process.

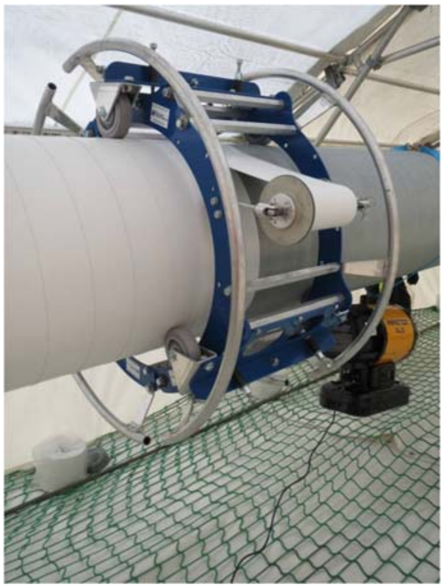

Figure 11 – Cable tape wrapping inside tent.

10. Closing remarks

The bridge was inaugurated and opened for public traffic on August 17, 2013 and from the very first day this new landmark in the Hardanger fjord was well used by both local and regional vehicles, heavy trucks and bicyclists.

Figure 12 – Traffic on opening day August 17, 2013.