Floating bridge
E39 Bjørnafjorden

Øyvind Nedrebø
Design Manager
Previously:

- Ship channel centre
- Two pylons on floating pontoons

Improved design – Ship channel moved south:
- Only one pylon required
- Pylon on land, safe from ship collision
Floating Bridge, E39 Bjørnafjorden

Curved bridge:

Straight bridge:

Status May 2016; Conceptual design developed for:

- **Curved bridge.** Bridge supported at each end, similar to the existing floating bridges in Norway, Bergsøysundet bru (1992) and Nordhordlandsbrua (1994)

- **Straight bridge.** Bridge supported each end, and additionally through pre-tensioned mooring lines
Curved Bridge:

- Length (overall): 4659 m
- Number of pontoons: 19
- Steel: 119 000 T
- Concrete: 146 000 m³
- Steel cables (cable-stayed bridge): 1900 T
Curved Bridge, Ship Channel:
Cable–Stay Part, Space: 45 m x 400 m

Comparison Sotrabrua:
- Ship channel: 49 m x 415 m
- Main ship route to Bergen from south
Curved Bridge. Box Girder

Double box girder connected through transverse box beams

Transverse beams spacing: 49,25 m
Curved Bridge Abutment at North End ( "Flua", −40 m)

Bridge girder connection

Concrete Gravity Base (GBS) Structure
Solid ballast placed in inside compartments
Curved Bridge Abutment at South End

- 1350 nos. Ø22 shear studs
- Cross beam 8m x 5m
- Inner transverse wall, 0.4m
- Outer transverse wall, 0.8m
- Saturated sand ballast
- Section A-A
- 6-19 strand posttensioned cable tensioned to 3675kN
Curved Bridge. Pontoons
Side Anchored Bridge

- Length (overall): 4506 m
- Number of pontoons: 18
- Steel: 80 100 T
- Concrete: 130 000 m³
- Cables (cable-stayed bridge): 1050 T
- Mooring lines: 24
Side Anchored Bridge. Bridge Girder
1. Introduction

2. Bridge Anchoring. Conditions at Site

3. Bridge Construction

4. Ship Collision

5. Pontoon Optimisation
**Bjørnafjorden Seabed Mapping**

Acoustic survey, March–April 2016

**Seabed: 0.5 m resolution**

Detailed depth mapping using ROV (multibeam echosounder)

Detailed image of the seabed and the depth variability
Subsea Slides, Soft Clay

Depth data (xyz) clearly reveal many historical slide scars and debris lobes.
Side Anchored Bridge. Reveal Feasible Anchor Locations

Bathymetry map. Bridge lines West (W) and East (E). Bridge tower marked by yellow star

Slope stability: Portion of slope that fails

S1: FS = 1.22, FS_{ps} = 1.08

S2: FS = 1.38, FS_{ps} = 1.23
Shown left:
Suggested anchor locations (2016) (NGI)

Remaining work to confirm preferred anchor locations to be continued in next design phase (2017)

An iterative procedure which also involves global dynamic analyses of moored bridge system
Floating Bridge, E39 Bjørnafjorden

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Construction. Part 1: Cable-stayed Bridge

Side span assembly: Crane vessel lift bridge girder elements onto temporary column supports

Similar to Höga Kusten bridge (Sweden)
Construction. Part 1: Cable-stayed Bridge
Ship channel span assembly

Similar to 3rd Bosphorous bridge, Turkey

Bridge girder elements (20 m) lifted from barge using strand jacks
Construction. Part 2: Pontoons and Abutment at Flua

In dry-dock and/or on barge (pontoon)

Simple installation of abutment at Flua (−40 m):
Construction. Part 3: Floating Bridge Assembly

Site assumed: Eikelandsfjorden, Fusa:
Construction. Part 3: Floating Bridge Assembly

The elevated south end (interfacing high bridge) requires crane for assembly. Construction similar to Sundsvall bridge (Sweden)
Construction. Part 4: Bridge Towing Operation

Total required towing capacity: 1300 T
(Storm condition, holding criteria according to Rules)

Selected: 14 vessels each 125 T pull capacity
→Towing speed 1.0–1.5 knots
Construction. Part 5: Bridge Installation

Weather criteria:
- Wind: 10 m/s
- Wave: 0.5 m (significant wave height)

Weather window required:
- Planned duration: 48 hrs
- Contingency: 48 hrs
- Total: 96 hrs

Pre-installed abutment and bridge segment at north end ("Flua")

Nordhordlandsbrua
1. Winches located on cable stayed bridge and bridge element at north end.

2. Winches pull the bridge gently towards bridge ends. Vessels assist in holding as needed.

3. Prior to connection a guide system at each end is used
1. Introduction

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Part A: Relevant Collision Energy

Collision risk analyses

Simulate one million year of ship traffic based on AIS recorded traffic data from the area.

Failure modes considered:

1. Rudder failure
2. Propulsion failure
3. Rudder and propulsion failure
4. Human error

Automatic Identification System (AIS):
Mandatory system used to avoid ship collisions.

Ship data such as ship registration number, position, speed, heading, etc. are exchanged through the VHF channel.
Part A: Determine Collision Energy for Design

Even distribution of the $10^{-4}$ level: 101.1 MJ

- **Preliminary**
- **Pontoon collision**
- **Girder collision**

$E = \frac{1}{2}mv^2$

100 MJ

- Ship channel

North

South
Part B: Ship impact. Structural resistance

Cruise ship:
- Mass: 24 344 T
- Length: 195.8 m
- Width: 22.5 m

Table 1. Material properties

<table>
<thead>
<tr>
<th>Items</th>
<th>Ship</th>
<th>Girder</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density</td>
<td>7850 kg/m³</td>
<td>7850 kg/m³</td>
</tr>
<tr>
<td>Young's modulus</td>
<td>210 GPa</td>
<td>210 GPa</td>
</tr>
<tr>
<td>Poisson’s ratio</td>
<td>0.3</td>
<td>0.3</td>
</tr>
<tr>
<td>Yield stress</td>
<td>275 MPa</td>
<td>563 MPa</td>
</tr>
<tr>
<td>Strength index (K)</td>
<td>740 MPa</td>
<td>845 MPa</td>
</tr>
<tr>
<td>Strain index (n)</td>
<td>0.24</td>
<td>0.135</td>
</tr>
</tbody>
</table>

Figure 1. FE model of the ship bow, (a) ship bow, (b) internal structures.
Part B: Ship impact. Structural resistance

Wall thickness 110 cm

335 MJ
110 MJ
90 MJ
Maritime Safety. Collaboration NCA

Objective:

• Establish representative input for the ship collision risk analyses

• Develop rule proposal for future traffic regulations in Bjørnafjorden

NCA pilots to run navigation simulator: Curved floating bridge modelled and imported into data base, ref.: «Den Virtuelle Sjøveien», http://dvs.hials.no/

NTNU – Senter for simulering og visualisering
Floating Bridge, E39 Bjørnafjorden

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5. Pontoon Optimisation
Pontoon Optimisation (case: Curved Bridge)

Each pontoon shall:
• Carry superstructure = 6000 T
• Carry self-weight (concrete) = 12000 T
• Resist large ship impact → Thick wall
• Have displacement adequate for ship impact

Other criteria applicable:

<table>
<thead>
<tr>
<th>Motions and deflections</th>
<th>Load condition</th>
<th>Limit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vertical deflection</td>
<td>70% of characteristic traffic load</td>
<td>1.0 m</td>
</tr>
<tr>
<td>Rotation about longitudinal axis due to traffic</td>
<td></td>
<td>1.0 deg</td>
</tr>
<tr>
<td>Rotation about longitudinal axis due to environmental loads</td>
<td>1 year storm</td>
<td>1.5 deg</td>
</tr>
<tr>
<td>Vertical acceleration</td>
<td></td>
<td>0.5 m/s²</td>
</tr>
<tr>
<td>Horizontal acceleration</td>
<td></td>
<td>0.5 m/s²</td>
</tr>
</tbody>
</table>
**Wind Waves**

Fetch distances, NW: 19.0 km, E: 21.5 km

<table>
<thead>
<tr>
<th>Location</th>
<th>1 year Hs [m]</th>
<th>1 year Tp [s]</th>
<th>10 year Hs [m]</th>
<th>10 year Tp [s]</th>
<th>100 year Hs [m]</th>
<th>100 year Tp [s]</th>
<th>1 000 year Hs [m]</th>
<th>1 000 year Tp [s]</th>
<th>10 000 year Hs [m]</th>
<th>10 000 year Tp [s]</th>
</tr>
</thead>
<tbody>
<tr>
<td>A1 (South)</td>
<td>1.5</td>
<td>4.4–5.5</td>
<td>2.6</td>
<td>5.0–6.0</td>
<td>3.2</td>
<td>5.6–6.4</td>
<td>3.9</td>
<td>6.1–6.8</td>
<td></td>
<td></td>
</tr>
<tr>
<td>A2</td>
<td>1.5</td>
<td>4.4–5.5</td>
<td>2.6</td>
<td>5.0–6.0</td>
<td>3.2</td>
<td>5.6–6.4</td>
<td>3.9</td>
<td>6.1–6.8</td>
<td></td>
<td></td>
</tr>
<tr>
<td>A3</td>
<td>0.5</td>
<td>4.4–5.5</td>
<td>2.6</td>
<td>5.0–6.0</td>
<td>3.2</td>
<td>5.6–6.4</td>
<td>3.9</td>
<td>6.1–6.8</td>
<td></td>
<td></td>
</tr>
<tr>
<td>A4</td>
<td>1.2</td>
<td>4.4–5.5</td>
<td>2.6</td>
<td>5.0–6.0</td>
<td>3.2</td>
<td>5.6–6.4</td>
<td>3.9</td>
<td>6.1–6.8</td>
<td></td>
<td></td>
</tr>
<tr>
<td>A5 (North)</td>
<td>1.2</td>
<td>3.8–5.0</td>
<td>1.5</td>
<td>3.8–5.5</td>
<td>1.9</td>
<td>4.3–6.0</td>
<td>2.3</td>
<td>4.7–6.4</td>
<td>2.6</td>
<td>5.1–6.8</td>
</tr>
</tbody>
</table>

Hs, significant wave height (ref. Wikipedia): The mean wave height (trough to crest) of the highest third of the waves

Tp, wave period
Ocean Waves (Swell)

<table>
<thead>
<tr>
<th>Return period / Location</th>
<th>1 year</th>
<th>10 year</th>
<th>100 year</th>
<th>1 000 year</th>
<th>10 000 year</th>
</tr>
</thead>
<tbody>
<tr>
<td>A1 (South)</td>
<td>0.06</td>
<td>0.08</td>
<td>0.10</td>
<td>0.12</td>
<td>0.13</td>
</tr>
<tr>
<td>A2</td>
<td>0.07</td>
<td>0.08</td>
<td>0.10</td>
<td>0.12</td>
<td>0.13</td>
</tr>
<tr>
<td>A3</td>
<td>0.16</td>
<td>0.21</td>
<td>0.25</td>
<td>0.29</td>
<td>0.33</td>
</tr>
<tr>
<td>A4</td>
<td>0.20</td>
<td>0.26</td>
<td>0.31</td>
<td>0.37</td>
<td>0.42</td>
</tr>
<tr>
<td>A5 (North)</td>
<td>0.17</td>
<td>0.21</td>
<td>0.26</td>
<td>0.30</td>
<td>0.34</td>
</tr>
</tbody>
</table>
Wave Load Spectrum used

JONSWAP spectrum for scatter diagram contour line

- Spectral density [m^2 / Hz]
- Period [s]

- Tp=3s, Hs=0.9m
- Tp=4s, Hs=1.6m
- Tp=5s, Hs=2.5m
- Tp=6s, Hs=3m
- Tp=12s, Hs=0.4m
- Tp=14s, Hs=0.4m
- Tp=16s, Hs=0.4m
Pontoon Optimisation. Part 1: Heave Response

Heave added mass with flange

Heave added mass without flange

Eigen period range with flange

Eigen period range without flange

Flange
Ongoing work – Objective:
Improve pontoon geometry to limit the amount of additional steel required for the south elevated part of the bridge girder.
Risk Based Verification

216 *Verification* is confirmation by examination and provision of objective evidence that specified requirements have been fulfilled (ISO 8402: 1994).

**Guidance note:**
The examination shall be based on information, which can be proved true, based on facts obtained through observation, measurement, test or other means.

See also *Certification.*
Floating Bridge, E39 Bjørnafjorden

Takk for oppmerksomheten!