The Submerged Floating Tube Bridge (SFTB)

Teknologidagene – Trondheim September 2016

SFTB for crossing the Bjoernafjord– Statens vegvesen
Why a SFTB

The challenges: Bjørnafjord

Solutions for the crossing

Conclusions
WHY A SFTB?

.. a hidden bridge able to preserve the landscape

SFTB with pontoons for crossing the Bjørnafjord– Statens vegvesen
THE CHALLENGES

Long and deep fjords

SFTB alignment– Statens vegvesen

 depth

~500 m
E39: the requirements

General tube section
Sections without lay-by (T9.5)

General tube section
Sections with lay-by (T12.5)

SFTB cross section – Statens vegvesen
Environmental loads

The Bjørnafjord – Google map

SINTEF – metocean conditions

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# Environmental loads

## Current velocities

<table>
<thead>
<tr>
<th>Depth</th>
<th>10 year</th>
<th>100 year</th>
<th>10000 year *</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surface</td>
<td>1.13 m/s</td>
<td>1.33 m/s</td>
<td>1.69 m/s</td>
</tr>
<tr>
<td>30 m</td>
<td>0.46 m/s</td>
<td>0.54 m/s</td>
<td>0.69 m/s</td>
</tr>
</tbody>
</table>

## Wind induced waves

<table>
<thead>
<tr>
<th>Return period</th>
<th>Scaling from 100 y</th>
<th>Hs (m)</th>
<th>Tp, min (s)</th>
<th>Tp, max (s)</th>
<th>γ (-)</th>
<th>Spread</th>
<th>Dir (deg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 y</td>
<td>0.67</td>
<td>2.0</td>
<td>4.0</td>
<td>6.0</td>
<td>2 - 4</td>
<td>5 - 10</td>
<td>330°</td>
</tr>
<tr>
<td>10 y</td>
<td>0.81</td>
<td>2.4</td>
<td>4.0</td>
<td>6.0</td>
<td>2 - 4</td>
<td>5 - 10</td>
<td>330°</td>
</tr>
<tr>
<td>100 y</td>
<td>1.00</td>
<td>3.0</td>
<td>4.0</td>
<td>6.0</td>
<td>2 - 4</td>
<td>5 - 10</td>
<td>330°</td>
</tr>
<tr>
<td>1000 y</td>
<td>1.19</td>
<td>3.6</td>
<td>4.0</td>
<td>6.0</td>
<td>2 - 4</td>
<td>5 - 10</td>
<td>330°</td>
</tr>
<tr>
<td>10000 y</td>
<td>1.29</td>
<td>3.9</td>
<td>4.0</td>
<td>6.0</td>
<td>2 - 4</td>
<td>5 - 10</td>
<td>330°</td>
</tr>
</tbody>
</table>

## Swell (wave height)

<table>
<thead>
<tr>
<th>Return period</th>
<th>Scaling from 100 y</th>
<th>Hs (m)</th>
<th>Tp, range (s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 y</td>
<td>0.63</td>
<td>0.19</td>
<td>12-16</td>
</tr>
<tr>
<td>10 y</td>
<td>0.81</td>
<td>0.24</td>
<td>12-16</td>
</tr>
<tr>
<td>100 y</td>
<td>1.00</td>
<td>0.30</td>
<td>12-16</td>
</tr>
<tr>
<td>1000 y</td>
<td>1.16</td>
<td>0.35</td>
<td>12-16</td>
</tr>
<tr>
<td>10000 y</td>
<td>1.31</td>
<td>0.39</td>
<td>12-16</td>
</tr>
</tbody>
</table>
Environmental loads

N400 Environmental loads (wave, current, tide and wind) must be considered as one load group with one load factor, considering 100 year return period for all environmental loads

Deflections

<table>
<thead>
<tr>
<th>Direction</th>
<th>Total deflection</th>
</tr>
</thead>
<tbody>
<tr>
<td>Horizontal</td>
<td>L / 200</td>
</tr>
<tr>
<td>Vertical</td>
<td>L / 350</td>
</tr>
</tbody>
</table>

distance between abutments
distance between vertical supports

Accelerations and vibrations

<table>
<thead>
<tr>
<th>Vibration</th>
<th>m/s²</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vertical</td>
<td>0.5</td>
</tr>
<tr>
<td>Horizontal</td>
<td>0.3</td>
</tr>
</tbody>
</table>
Fires and explosions

- Detonation
- Deflagration

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Ship and submarine impact

SSPA study for Bjørnafjorden – Statens vegvesen

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- 30 m
Wave loads with water depth (normalized)
.. every 200 m

SFTB safety exits – Statens vegvesen
• Ship and submarine collisions
• Visual impact
• Neutrally buoyant, the vertical stiffness is the water line area of the pontoons
• Higher vertical flexibility

• No ship collision
• No visual impact
• Neutrally buoyant; tethers pre-stressed (no loss of tension)
• Soil characteristics
SFTB with pontoons – Statens vegvesen
SFTB with tethers – Statens vegvesen
FEM model for submarine collision and for submarine—Statens vegvesen

SFTB verified for central hit and an eccentric hit

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SFTB with pontoon – Statens vegvesen

Section A-A 1:300

Section B-B 1:300

Section C-C 1:300

Plan view 1:300

Plan view 1:300

Plan view 1:300

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### Return period vs Impact energy

<table>
<thead>
<tr>
<th>Return period</th>
<th>Impact energy</th>
</tr>
</thead>
<tbody>
<tr>
<td>100 years</td>
<td>-</td>
</tr>
<tr>
<td>1 000 years</td>
<td>0.3 MJ</td>
</tr>
<tr>
<td>10 000 years</td>
<td>339 MJ</td>
</tr>
<tr>
<td>100 000 years</td>
<td>725 MJ</td>
</tr>
</tbody>
</table>

**Accidental scenario**

**40 000 ton displacement vessel**

[Graph showing energy and impulse force over time]

**Abaqus**

Impulse force and energy on pontoon – Statens vegvesen

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- Outer diameter: 1118 mm
- Wall thickness: 38 mm
- Tether resistance: 27 MN (S235)
- Nominal pre-tension: 10.5/11.0 MN

Tethers for SFTB – Statens vegvesen

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Foundations

SFTB foundations – Statens vegvesen

Bjørnafjord sediment thickness (April 2016) – Statens vegvesen

Olivine + Structure
Subm. weight 60 MN

Gravity anchor soft clay

Drilled and grouted piles – each with 20 MN vert. capacity

Drilled into rock

Gravity anchor Moraine/mixed soils
SFT: drilled and grouted rock anchors – Statens vegvesen
Wind tunnel test: stable behaviour under current and wave actions (less added mass than the rectangular section)
ROBUSTNESS:
ability of the structure to withstand unexpected situations

- A ship impact towards one pontoon. The pontoon is not removed during this event. The ship impact is modeled as a time domain transient dynamic analysis with correct mass, stiffness and damping relations.
- Instantaneous loss of one pontoon. No time for traffic redirecting or limitations are assumed, i.e. full traffic load in an accidental state. After this event the traffic load is reduced and the structure is controlled in a regular ultimate limit state.
- Sinking ship hitting the tubes. An approximation of maximum vessel weight is found.
- Explosion in the tubes in combination with other loads.
- Flooding in one of the ballast chambers.
- Loss of one tether.
Towing and installing procedure

SFTB: construction in dry docks – Statens vegvesen

SFTB: assembly phase – Statens vegvesen

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Towing and installing procedure

SFTB: installation phases – Statens vegvesen

SFTB installation – Statens vegvesen

Temporary towers – Statens vegvesen

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CONCLUSIONS

<table>
<thead>
<tr>
<th>Max vertical motion SLS</th>
<th>Acceleration 0.05 m/s²</th>
</tr>
</thead>
<tbody>
<tr>
<td>Max horizontal motion SLS</td>
<td>Acceleration 0.1 m/s²</td>
</tr>
</tbody>
</table>

Zero downtime due to weather

ALL THE FUNCTIONAL REQUIREMENTS ARE MET
WITH FULL TRAFFIC LOAD
DURING A 100 YEAR STORM
Submerged Floating Tube Bridge in Bjørnafjorden – Statens vegvesen

SFTB cross section

SFTB cycle and pedestrian path – Statens vegvesen

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Statens vegvesen – study for the SFTB in Bjørnafjord

Thank you for your attention

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