The development of a floating bridge – Bjørnafjorden

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Presentation contents

Bjørnafjorden project’s:

- Brief history
- Current phase & ongoing research
- Upcoming phase
E39 Coastal Highway Route

Bjørnafjorden
Bjørnafjorden

Phase: 1 – 2 – 3 – 4 – 5 – ...

Alternative pathways
Bjørnafjorden
Phase: 1 – 2 – 3 – 4 – 5 – ...

Concept study
Bjørnafjorden
Phase: 1 – 2 – 3 – 4 – 5 – ...
Concept study – floating bridge
Bjørnafjorden

Phase: 1 – 2 – 3 – 4 – 5 – …

Concept study – floating bridge
Bjørnafjorden
Phase: 1 – 2 – 3 – 4 – 5 – ...
Concept study – floating bridge
Bjørnafjorden

Phase: 1 - 2 - 3 - 4 - 5 - ...

Concept study – floating suspension bridge
Bjørnafjorden
Phase: 1 - 2 - 3 - 4 - 5 - ...
Bjørnafjorden

Phase: 1 – 2 – 3 – 4 – 5 – ...

Concept study – floating suspension bridge

... | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 ...
Concept study – submerged floating tube bridge
Bjørnafjorden

Phase: 1 – 2 – 3 – 4 – 5 – ...

Concept study – submerged floating tube bridge
Bjørnafjorden

Phase: 1 - 2 - 3 - 4 - 5 - ...

Concept study – submerged floating tube bridge
Bjørnafjorden

Phase: 1 – 2 – 3 – 4 – 5 – ...

Concept study – suspension bridge
Bjørnafjorden
Phase: 1 – 2 – 3 – 4 – 5 – ...
Concept study – suspension bridge
Bjørnafjorden
Phase: 1 – 2 – 3 – 4 – 5 – ...
Concept study – suspension bridge
Bjørnafjorden

Phase: 1 – 2 – 3 – 4 – 5 – ...

Concept study – a few others…
Bjørnafjorden

Phase: 1 – 2 – 3 – 4 – 5 – ...

Concept choice

Phase: 1 2 3 4 5

Floating bridge

Floating suspension bridge

Submerged floating tube bridge

Suspension bridge
Bjørnafjorden
Phase: 1 – 2 – 3 – 4 – 5 – ...

Floating bridge – curved
Bjørnafjorden
Phase: 1 – 2 – 3 – 4 – 5 – ...
Floating bridge – straight
Bjørnafjorden
Phase: 1 – 2 – 3 – 4 – 5 – ...
Floating suspension bridge
Bjørnafjorden

Phase: 1 – 2 – 3 – 4 – 5 – …

Submerged floating tube bridge
Bjørnafjorden
Phase: 1 – 2 – 3 – 4 – 5 – ...
Submerged floating tube bridge
Bjørna fjorden
Phase: 1 – 2 – 3 – 4 – 5 – ...
Submerged floating tube bridge
Concept choice

Bjørnafjorden
Phase: 1 – 2 – 3 – 4 – 5 – ...

Floating bridge
Floating suspension bridge
Submerged floating tube bridge
Suspension bridge
Bjørnafjorden

Phase: 1 - 2 - 3 - 4 - 5 - ...

Floating bridge – curved
Bjørnafjorden
Phase: 1 – 2 – 3 – 4 – 5 – ...
Floating bridge – curved
Bjørnafjorden

Phase: 1 – 2 – 3 – 4 – 5 – ... 

Floating bridge – straight
Bjørnafjorden

Phase: 1 – 2 – 3 – 4 – 5 – ...

Floating bridge – straight
Bjørnafjorden
Phase: 1 – 2 – 3 – 4 – 5 – …
Floating suspension bridge
Concept choice

Phase: 1 – 2 – 3 – 4 – 5 – ...

**Floating bridge**

**Floating suspension bridge**

**Submerged floating tube bridge**

**Suspension bridge**

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**Bjørnafjorden**

Phase: 1 – 2 – 3 – 4 – 5 – ...

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Bjørnafjorden
Phase: 1 – 2 – 3 – 4 – 5 – …
Further developing the design basis.
A few examples:

- Wind, waves, currents and temperature measurements.
Bjørnafjorden

Phase: 1 – 2 – 3 – 4 – 5 – ...

Further developing the design basis.
A few examples:

- Vehicle–bridge motions: comfort and safety.

\[ y(t) = \sin \left( \frac{v(t)}{\lambda} t \right) \cdot 2\pi \cdot \sum_n \sin(\omega_n t + \psi_n) \]
Bjørnafjorden

Phase: 1 – 2 – 3 – 4 – 5 – ...

Further developing the design basis. A few examples:

- Fatigue load model: traffic measurements.

Real traffic? Measurements Load models
Bjørnafjorden
Phase: 1 – 2 – 3 – 4 – 5 – ...
Further developing the design basis. A few examples:

- Ship impact: risk and consequence.
Bjørnafjorden
Phase: 1 – 2 – 3 – 4 – 5 – …
Further developing the design basis. A few examples:

- Bedrock and bathymetry investigations.
Bjørnafjorden
Phase: 1 – 2 – 3 – 4 – 5 – ...
Further developing the design basis.
A few examples:

- Wave model tests
Bjørnafjorden

Phase: 1 – 2 – 3 – 4 – 5 – ...

Further developing the design basis.
A few examples:

- Wind model tests: skew winds, static coefficients.
Bjørnafjorden
Phase: 1 – 2 – 3 – 4 – 5 – ...
Further developing the design basis.
A few examples:

- Wind and wave-induced-turbulence
Bjørnafjorden
Phase: 1 - 2 - 3 - 4 - 5 - ...

Further developing the design basis. A few examples:

- Dynamic buckling on a curved floating bridge

... | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 ...

wind
waves
currents
Bridge

Phase: 1 – 2 – 3 – 4 – 5 – ...

Dynamic buckling

**Eurocode 3 – Static buckling curves**

\[ N_{cr} \approx 0.1 \times N_{pl,Rd} \]
Bjørnafjorden

Dynamic buckling

Direct resonance VS Parametric resonance

\[ f_{\text{load}} = f_{\text{natural}} \]

Response:
Bjørnfjorden
Dynamic buckling
Direct resonance VS Parametric resonance

\[ f_{\text{load}} = 2 \times f_{\text{natural}} \]

Response:
increasing exponentially
Bjørnafjorden
Dynamic buckling

Generalized equation of motion

\[ \ddot{M} \ddot{y} + \ddot{C} \dot{y} + \left( \ddot{K} - \ddot{K}_G N(t) \right) y = \ddot{F}(t) \]

Axial force: \( N(t) = A \cos(2\omega_n t) \)

Generalized geometric stiffness: \( \ddot{K}_G = \int_0^L \left( \phi'(x) \right)^2 N(x) \, dx \)

Critical axial force amplitude: \( A_{cr,\text{harmonic}} = 4\xi \frac{\ddot{K}}{\ddot{K}_G} \)

Instability regions

Dynamic buckling, as a parametric excitation, depends on:

- Stiffness & geometric stiffness
- Axial force amplitude, frequency and duration
- Damping

Bjørnafjorden
Dynamic buckling
Harmonic loads & response.

1st mode

2nd mode

Axial force modelled as: $\Delta T(t) + \text{modal kinematic constraints}$

Dynamic buckling

$f_{load} = 2 \ f_{natural}$

... | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 ...

01.11.2018
Bjørnafjorden

Dynamic buckling
Harmonic loads & response. 1\textsuperscript{st} mode

Axial force amplitude $A$:

$A \approx 1\text{MN}$

$A \approx 2\text{MN}$

$A \approx 3\text{MN}$

$A \approx 4\text{MN}$

$A_{cr} \approx 2.4\text{ MN}$

$N_{cr,static} \approx 70\text{ MN}$ (compression)
Harmonic loads & response.

<table>
<thead>
<tr>
<th>MODE</th>
<th>$f_n$ [Hz]</th>
<th>$T$ [s]</th>
<th>$A_{cr, harmonic}$ [MN] (1% damping)</th>
<th>Damping</th>
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Stochastic loads & response. Stability criteria.

Dynamic buckling

Standard deviation of the axial force, for mode $m$

$$\sigma_{N,m} < \gamma A_{cr,harmonic,m}$$

$$\gamma = 0.5$$ [1]

Bjørnafjorden
Dynamic buckling
Stochastic loads & response. Worst cases of 100,000 simulations.

\[ \gamma = 0.4 \]

\[ \gamma = 0.6 \]

\[ \gamma = 1.0 \]
Bjørnafjorden
Dynamic buckling
Stochastic loads & response. All 100,000 simulations.

Gumbel plots

\[ \gamma = 0.4 \]
\[ \gamma = 0.6 \]
\[ \gamma = 1.0 \]
Bjørnafjorden
Dynamic buckling
Applying the criteria. Modal frequency ratios.

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- Frequency ratios close to 2

Example:
- mode 9 ~ 7sec
- mode 5 ~ 15sec

...| 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 ...
Bjørnafjorden
Dynamic buckling
Applying the criteria. Modal frequency ratios.

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</table>

- Frequency ratios close to 2
- Modes with anti-symmetric axial force distributions

Applying the criteria. Example.

Axial force response:

Band pass filtered response:

**Stability criteria:**

\[ \sigma_{N,n} < 0.5 A_{cr,n} \]
Bjørnafjorden
Phase: 1 – 2 – 3 – 4 – 5 – ...

Choosing a floating bridge concept

Alternative 1

Alternative 2

Alternative 3

Alternative 4

...| 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 ...
Bjørnafjorden
Phase: 1 – 2 – 3 – 4 – 5 – ...

Choosing a floating bridge concept

Consultant group X
1\textsuperscript{st} – Alternative a
2\textsuperscript{nd} – Alternative c
3\textsuperscript{rd} – Alternative b
4\textsuperscript{th} – Alternative d

Consultant group Y
1\textsuperscript{st} – Alternative c
2\textsuperscript{nd} – Alternative a
3\textsuperscript{rd} – Alternative b
4\textsuperscript{th} – Alternative d
Bjørnafjorden
Phase: 1 – 2 – 3 – 4 – 5 – ...

Choosing a floating bridge concept

Consultant group X

Consultant group Y

1\textsuperscript{st} – Alternative a
2\textsuperscript{nd} – Alternative b
3\textsuperscript{rd} – Alternative c
4\textsuperscript{th} – Alternative d

Pre-engineering phase

3\textsuperscript{rd} party check
Good luck, dedication and inspiration for the next phase!
Thank you for your attention.