WIND
ENGINEERING
FLUID
DYNAMICS

Coastal Highway E39

Teknologidagene 2018 – Trondheim

New generation of long-span suspension bridges

Kristoffer Hoffmann

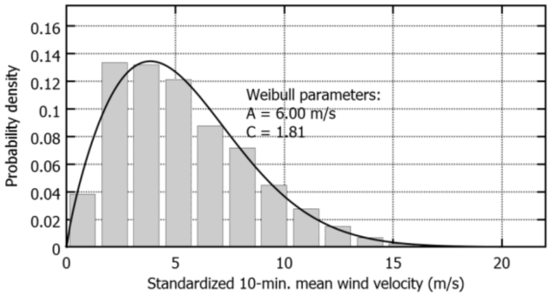
Svend Ole Hansen ApS, Copenhagen, Denmark

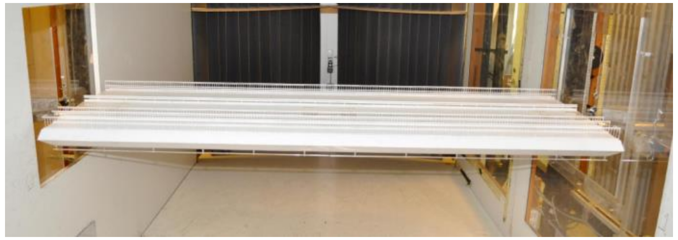
Svend Ole Hansen ApS

New generation of long-span suspension bridges

Our involvement with Coastal Highway Route E39 so far

- Wind field descriptions
- Wind tunnel testing
- Wind load calculations
- Full-scale measurements





$$\mathbf{A} \equiv \frac{1}{2\pi}\begin{pmatrix} \frac{1}{\tilde{x}_{C_1}-\tilde{x}_{\Gamma_1}} & \cdots & \frac{1}{\tilde{x}_{C_1}-\tilde{x}_{\Gamma_N}} & V_{\mathrm{w}}\left(K(\tilde{x}_{C_1}-\tilde{x}_{\mathrm{w}})\right) \\ \vdots & \ddots & \vdots & \vdots \\ \frac{1}{\tilde{x}_{C_N}-\tilde{x}_{\Gamma_1}} & \cdots & \frac{1}{\tilde{x}_{C_N}-\tilde{x}_{\Gamma_N}} & V_{\mathrm{w}}\left(K(\tilde{x}_{C_N}-\tilde{x}_{\mathrm{w}})\right) \\ -iK & \cdots & -iK & 1 \end{pmatrix},$$

$$\mathbf{\Gamma} \equiv \begin{pmatrix} \tilde{\Gamma}_1 \\ \vdots \\ \tilde{\Gamma}_N \\ \tilde{\gamma}_0 \end{pmatrix}, \qquad \mathbf{V} \equiv \begin{pmatrix} \dot{\tilde{y}} - K^{-1}\alpha - \tilde{x}_{C_1}\dot{\alpha} \\ \vdots \\ \dot{\tilde{y}} - K^{-1}\alpha - \tilde{x}_{C_N}\dot{\alpha} \\ 0 \end{pmatrix}.$$

New generation of long-span suspension bridges


1937: Golden Gate Bridge (1280 m)


1998: Great Belt Bridge (1624 m)


1998: Akashi Kaikyō Bridge (1991 m)

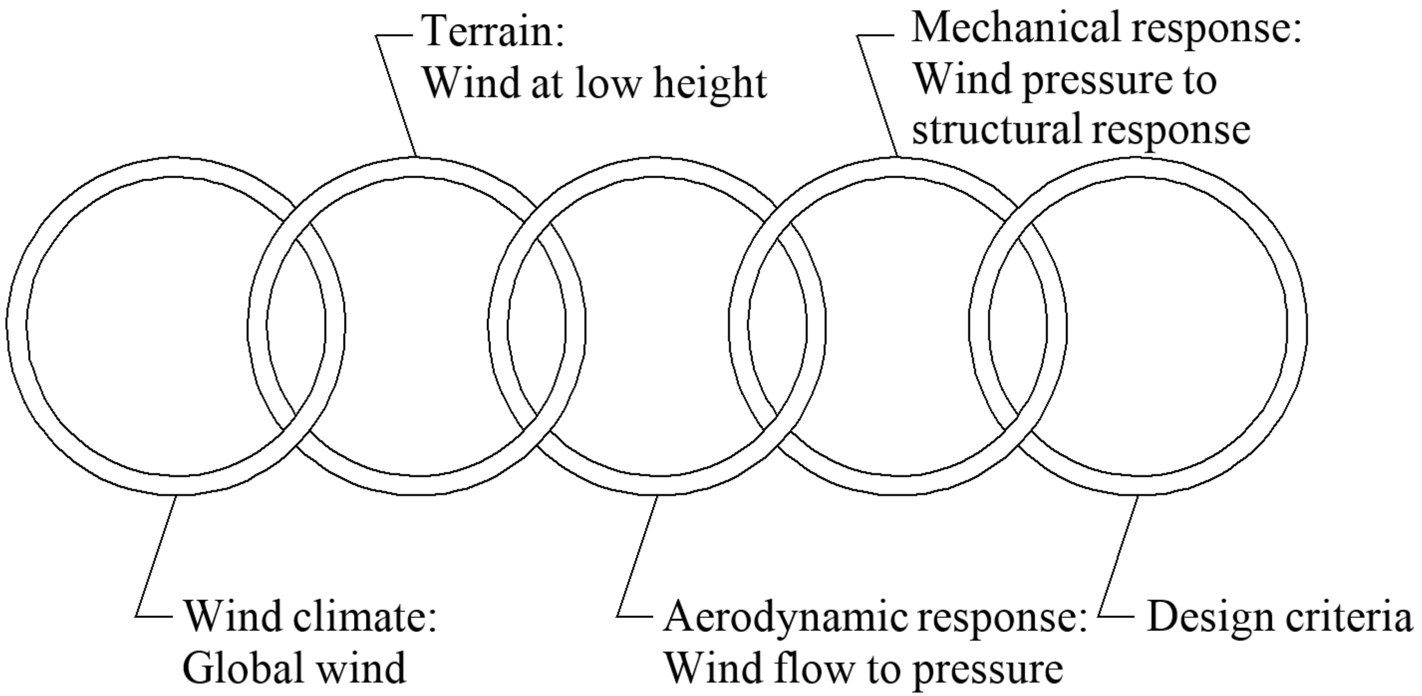
Spans above 2000 m challenge the existing technologies and methods

Q: How to design a long-span suspension bridge with "optimal" <u>aerodynamic</u> behavior?

A: Develop new <u>technology</u> to improve the understanding of wind loads and responses.

Development of new technology

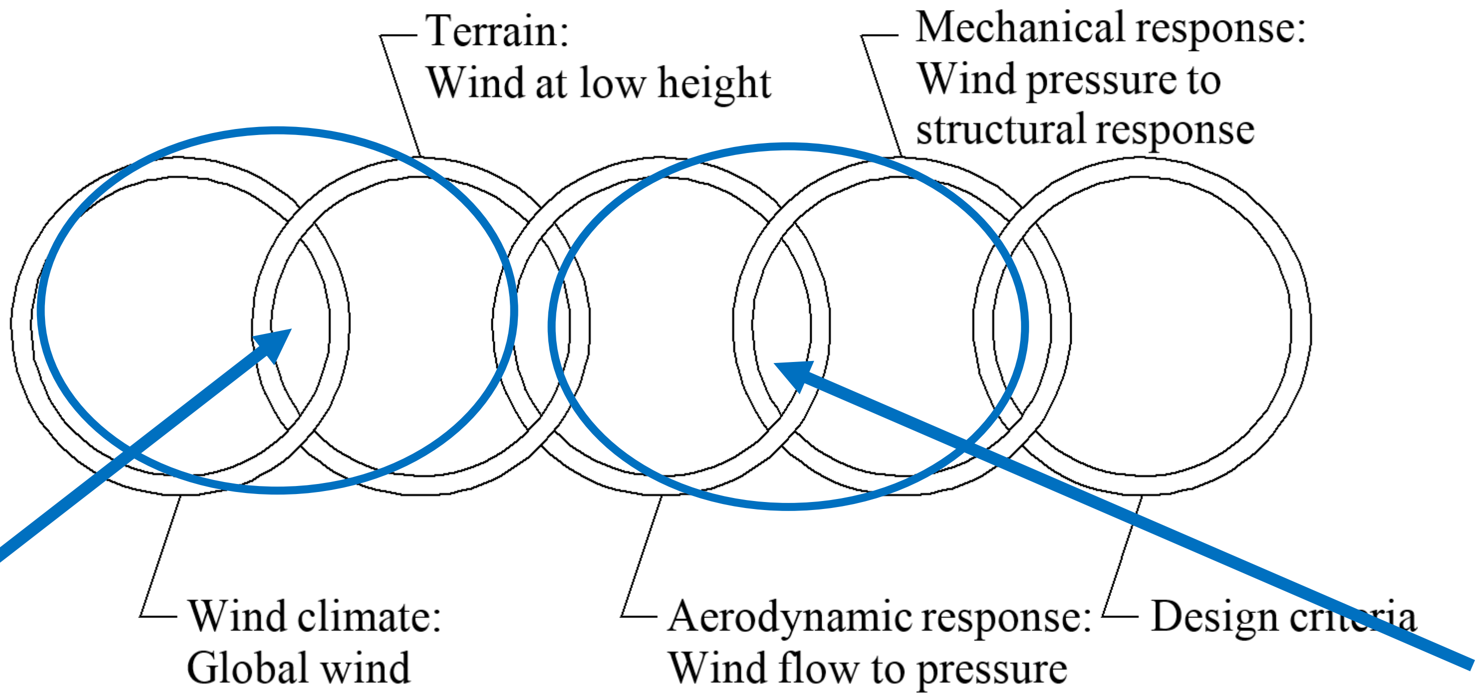
From wind climate to design criteria



New generation of long-span suspension bridges

Development of new technology

From wind climate to design criteria



Wind field description

Experimental methods
Calculation format

Development of new technology - Wind field descriptions

Basic models and parameters in the description of the wind field

- For calculating wind loads

New possibilities to measure and model wind

- Ultrasonic anemometers, LIDAR, SIMRA, …

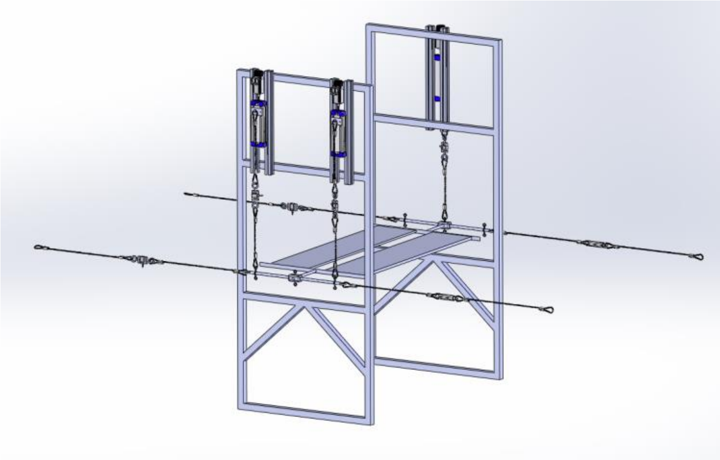
Probabilistic wind data format

- Physical understanding → Probabilistic models
- Probabilistic quantification of response*

**See paper from COTech 2017*

New generation of long-span suspension bridges

Development of new technology - Wind tunnel testing



Understand the wind loading mechanisms and magnitudes

- Section model tests: Spring-supported, forced-motion rig

Along-span characteristics are important

- Pressure taps: Along-span load correlation

Effect of additional elements

- Railing, windshields, traffic barriers, etc.

For other E39 bridge concepts

- Submerged floating tube bridge – Hydrodynamics, VIV*
- Floating bridge – Wave-induced vertical wind components

**See paper from Experimental Fluid Mechanics 2015*

New generation of long-span suspension bridges

Development of new technology – Calculation methodologies

The prediction of flutter

- Basic theory is derived from flat-plate considerations
- Aerodynamic derivatives (Reformulation?)

$$\mathbf{A} \equiv \frac{1}{2\pi}\begin{pmatrix} \frac{1}{\tilde{x}_{C_1}-\tilde{x}_{\Gamma_1}} & \cdots & \frac{1}{\tilde{x}_{C_1}-\tilde{x}_{\Gamma_N}} & V_{\mathrm{w}}\big(K(\tilde{x}_{C_1}-\tilde{x}_{\mathrm{w}})\big) \\ \vdots & \ddots & \vdots & \vdots \\ \frac{1}{\tilde{x}_{C_N}-\tilde{x}_{\Gamma_1}} & \cdots & \frac{1}{\tilde{x}_{C_N}-\tilde{x}_{\Gamma_N}} & V_{\mathrm{w}}\big(K(\tilde{x}_{C_N}-\tilde{x}_{\mathrm{w}})\big) \\ -iK & \cdots & -iK & 1 \end{pmatrix},$$

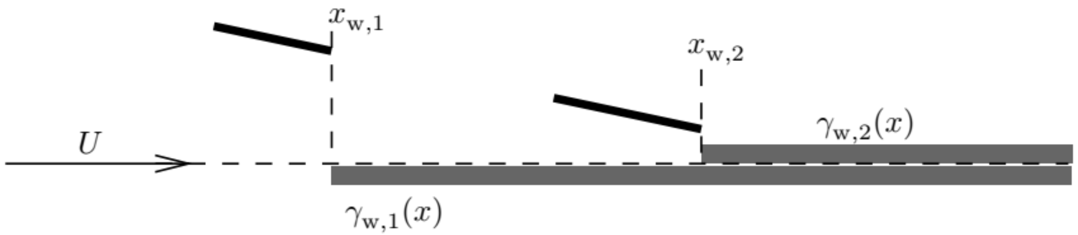
$$\boldsymbol{\Gamma} \equiv \begin{pmatrix} \tilde{\Gamma}_1 \\ \vdots \\ \tilde{\Gamma}_N \\ \tilde{\gamma}_0 \end{pmatrix}, \qquad \mathbf{V} \equiv \begin{pmatrix} \dot{\tilde{y}} - K^{-1}\alpha - \tilde{x}_{C_1}\dot{\alpha} \\ \vdots \\ \dot{\tilde{y}} - K^{-1}\alpha - \tilde{x}_{C_N}\dot{\alpha} \\ 0 \end{pmatrix}.$$

Buffeting loads

- Aerodynamic admittance*

Multi-segment flat-plate theory**

- Flat-plate representation of split-box girder



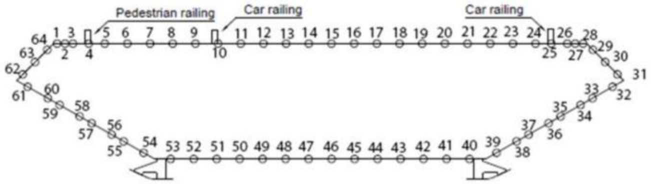
**See paper from Bluff Body Aerodynamics and Applications 2016*
***Submitted to "Journal of Wind Engineering and Industrial Aerodynamics"*

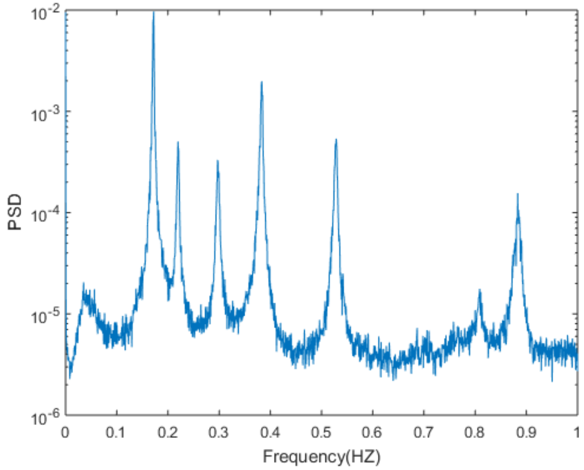
New generation of long-span suspension bridges

Development of new technology – Full-scale measurements

Further understand and verify the generation of wind loads and responses

- Undisturbed wind
- Wind-induced surface pressure
- Structural response





See paper from AAWE Workshop, August 2018

New generation of long-span suspension bridges

<u>Technology</u> is a key factor for the new generation of long-span suspension bridges


Halsafjorden crossing concept (Kristian Berntsen, SVV)

Development in all parts of the wind load chain

- Wind field
- Calculation methods
- Experimental methods

For the design of girder <u>cross section</u>

Norway leads the field in the technological development for suspension bridges

- Perspective: In 20-40 years - Top 3 of world's longest spans in Norway?

WIND
ENGINEERING
FLUID
DYNAMICS

Thank you for your attention

Svend Ole Hansen ApS