Halsafjorden Suspension Bridge
2050 m main span
Feasibility study

The focus of the feasibility study is to achieve a aerodynamic stable bridge

The structural design of steel and concrete is to obtain eigenmodes and frequencies

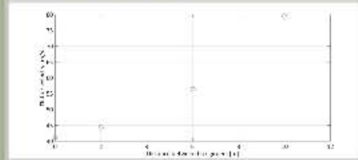
Wind tunnel tests

- Extensive wind tunnel testing is carried out by Svend Ole Hansen ApS
- TS1/VS1, TS1/VS2 and TA1/VA2 modes have been tested for flutter
- Various gap between boxes have been tested
- Vortex induces vibrations has proven to be an issue that is still being worked on
- The tests are done in a generic way in order to be used for more crossings than just Halsafjorden

Flutter velocity

- The combination VS2/TS1 does not couple, due to the low coupling coefficient
- VS1/TS1 and VA1/TA1 goes to flutter at approximately the same flutter velocity

Effect of gap on flutter velocity



Vortex induced vibrations

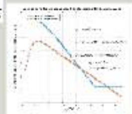
Quick recap on aerodynamic stability problems

Static divergence
- Governed by torsional frequency and the slope of Cm

Galloping
- Governed by the slope of Cl
- Not a problem on bridge girders

Dynamic stability limit in torsion
- A2* has to be positive
- A2* is always negative on flat plates

Flutter
- Coupling of vertical and torsional modes
- Governed by eigenmodes and aerodynamic derivatives



Future work

- The next phase is a preliminary study
- On-site geological surveys
- R&D to get a better understanding of aerodynamic stability problems
- Preliminary design of the main components to obtain a cost estimate

Design basis

Load factors and traffic loads

- Eurocode traffic loads are limited to 200 m, 500 m in National Appendix
- 9 kN/m per traffic lane, 2 kN/m per walkway, adding up to a total of 22 kN/m is used in the design of main cables and towers
- Load factors 1.2 for dead loads and 1.35 for traffic loads has been used in design of main cables
- Box girders and hangers are designed according to Eurocode traffic loads and load factors

Wind speed

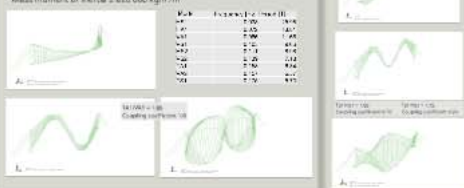
- Mean wind speed is estimated at of 36 m/s at 60 m above sea level, after 1,5 years of wind measurements on site
- Critical wind speed is defined as:

Outline of the bridge

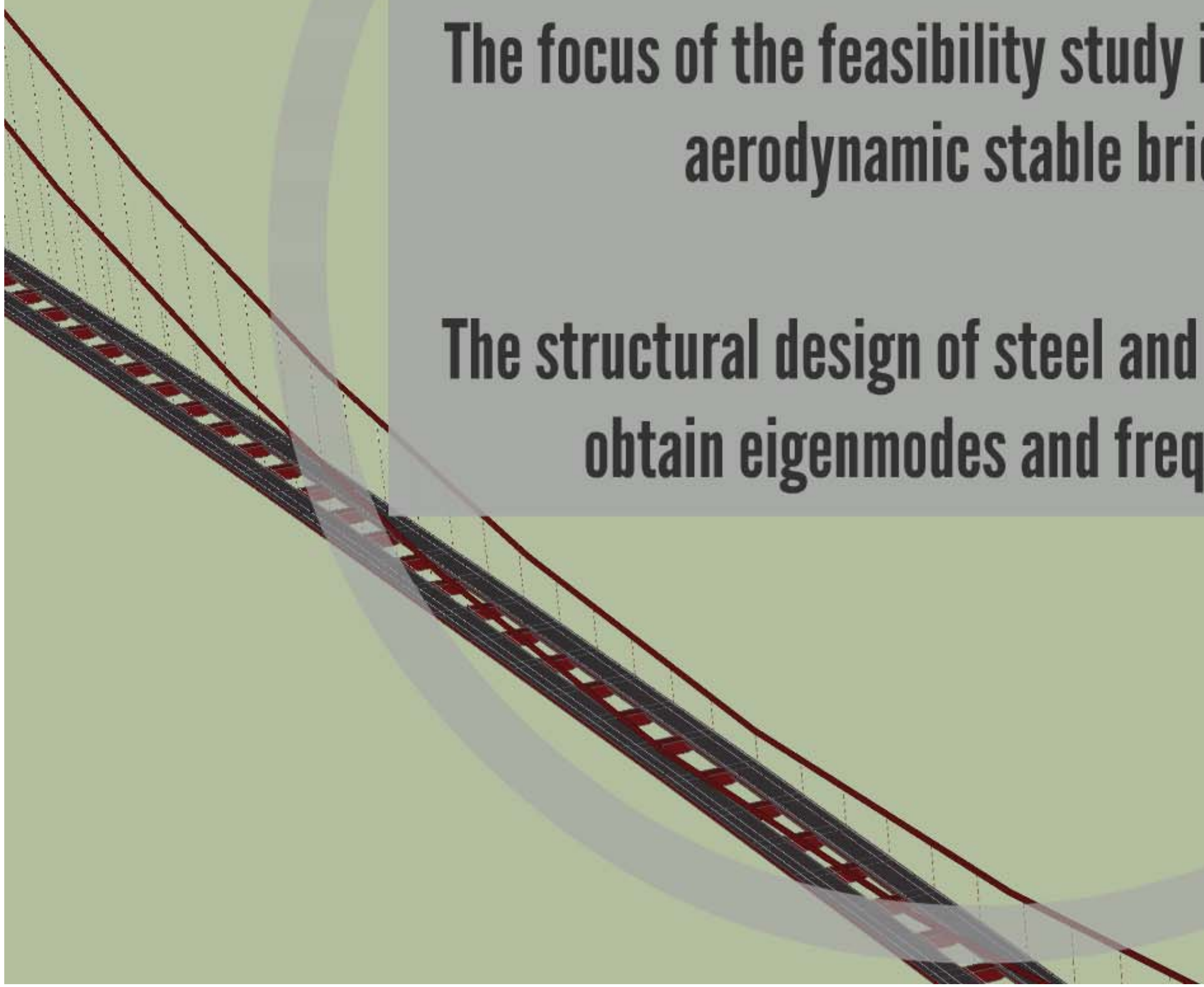
- Twin box-girder
- 30 m between hangers
- Cross-beam at each hanger
- ø100 mm hangers as full-locked coil ropes
- 265 m high concrete towers
- ø0.75 m suspension cables
  - 0.375 m² each
  - 1860 MPa tensile strength
  - Rock anchor at both ends

Eigen-frequencies

Total mass 19 920 kg/m
Mass moment of inertia 2 820 000 kgm²/m



Bjørn Isaksen
Directorate of Public Roads
Molde 17.12.2015



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Quick recap on aerodynamic stability problems

Static divergence

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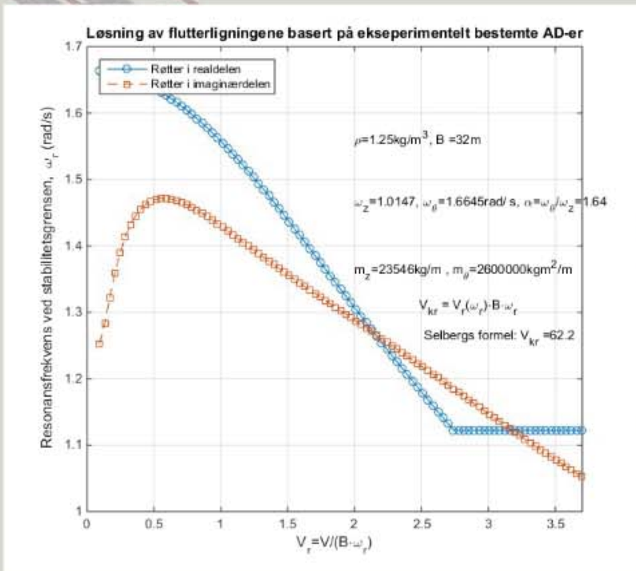
$$V_{kr} = 2\pi b n_\theta \sqrt{\frac{2m_\theta}{\rho b^4 C'_m}}$$



Galloping

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$$C'_L < -\bar{C}_D \cdot D / B$$

Dynamic stability limit in torsion

- A2* has to be positive
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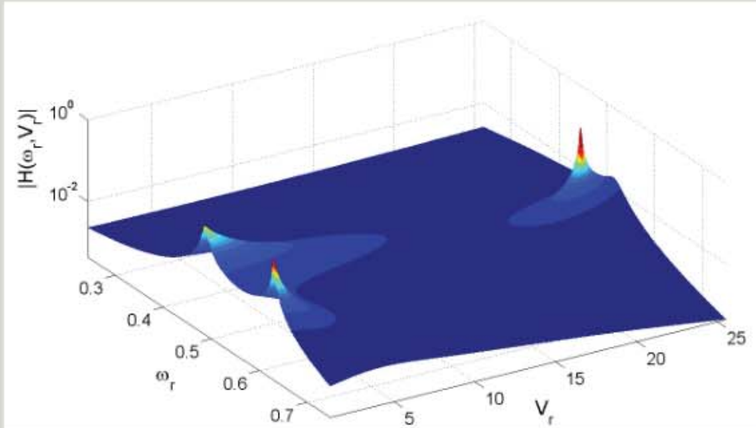
$$\zeta_\theta = \zeta_{ae_{\theta\theta}} = \frac{\rho B^4}{4\tilde{m}_\theta}\frac{\omega_r}{\omega_\theta} A_2^*$$

Flutter

- Coupling of vertical and torsional modes
- Governed by eigenmodes and aerodynamic derivatives.

$$\hat{\mathbf{E}}_\eta(\omega, V) = \left\{ \mathbf{I} - \boldsymbol{\kappa}_{ae} - \left(\omega \cdot diag\left[\frac{1}{\omega_i}\right]\right)^2 + 2i\omega \cdot diag\left[\frac{1}{\omega_i}\right] \cdot (\boldsymbol{\zeta} - \boldsymbol{\zeta}_{ae}) \right\}$$

$$\left|\det\left(\hat{\mathbf{E}}_\eta(\omega, V)\right)\right| = 0$$



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- Critical wind speed is defined as:

$$v_{crit} = 1.6 \cdot v_m(z = 60 \text{ m}, T = 600 \text{ s}, T = 500 \text{ years}) = 64{,}5 \text{ m/s}$$

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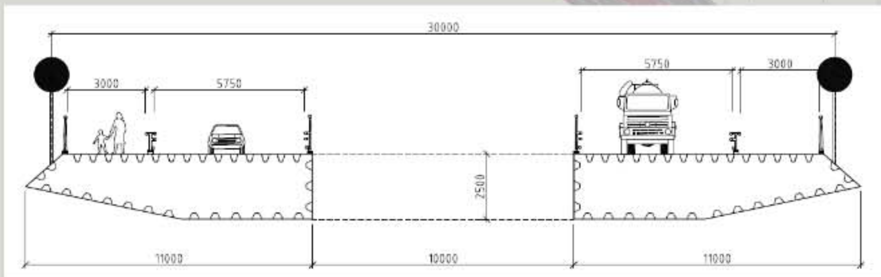

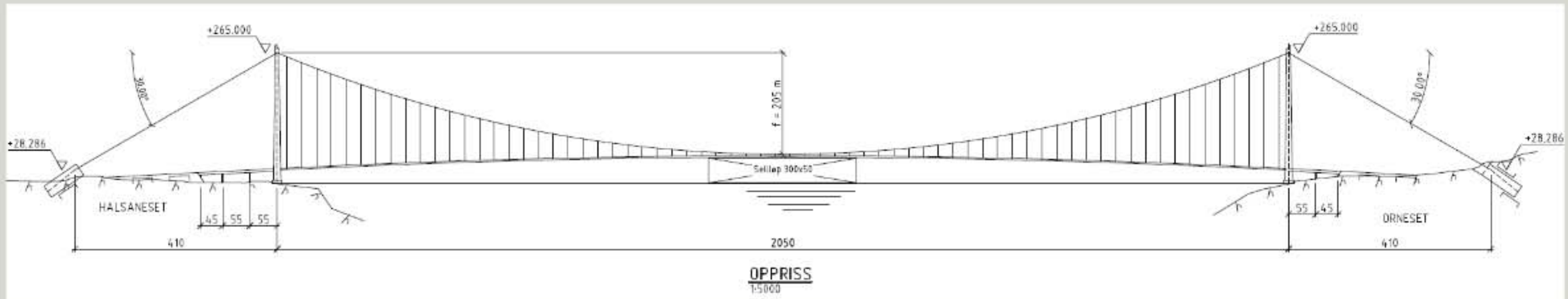

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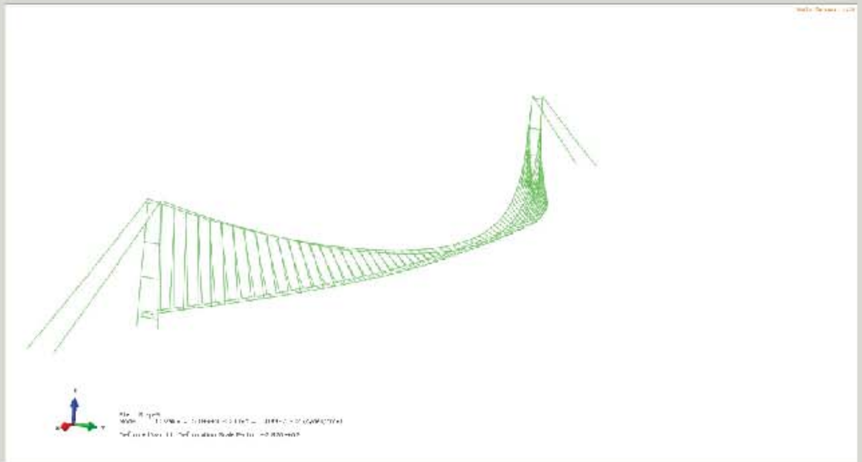
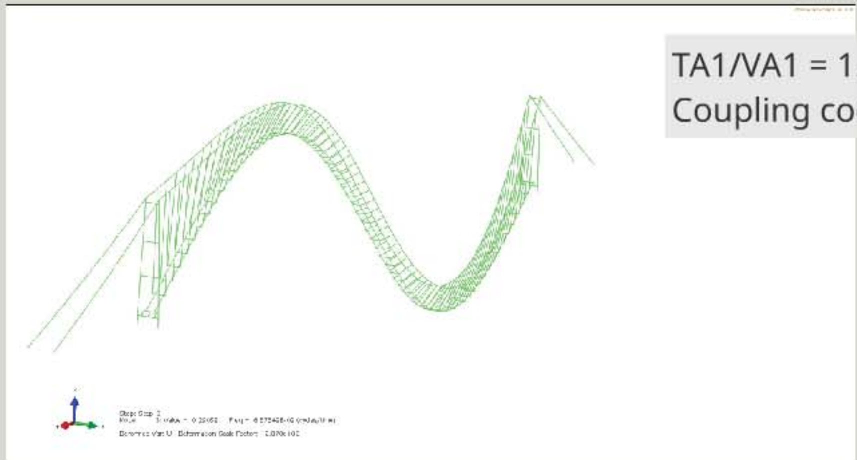
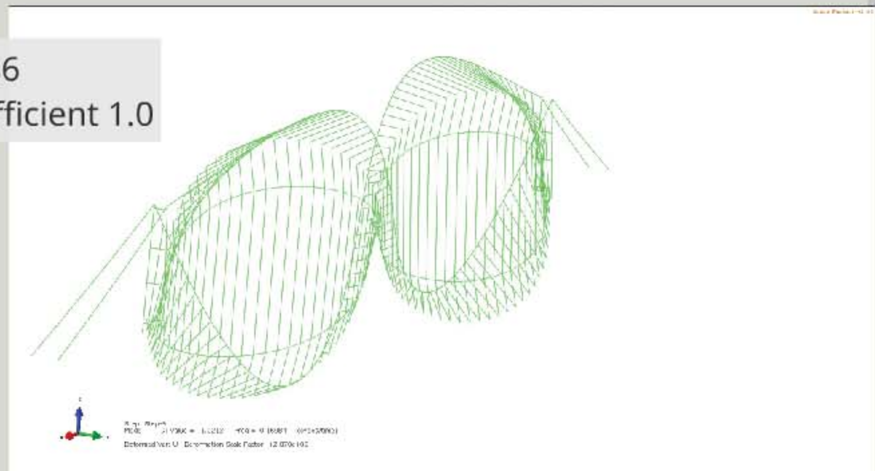


Mode	Frequency [Hz]	Period [T]
HS1	0.038	25.98
HA1	0.072	13.81
VA1	0.086	11.66
VS1	0.103	9.66
HS2	0.111	8.98
VS2	0.139	7.18
TA1	0.158	6.34
VA2	0.157	6.37
TS1	0.175	5.73



TA1/VA1 = 1.86

Coupling coefficient 1.0



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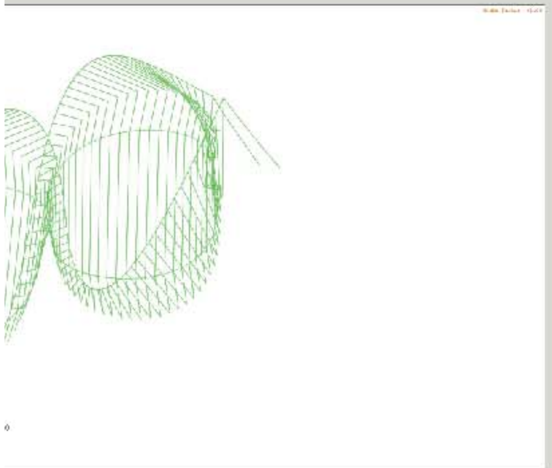
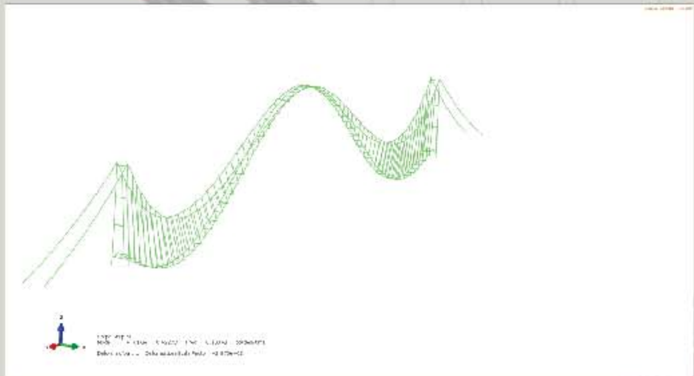
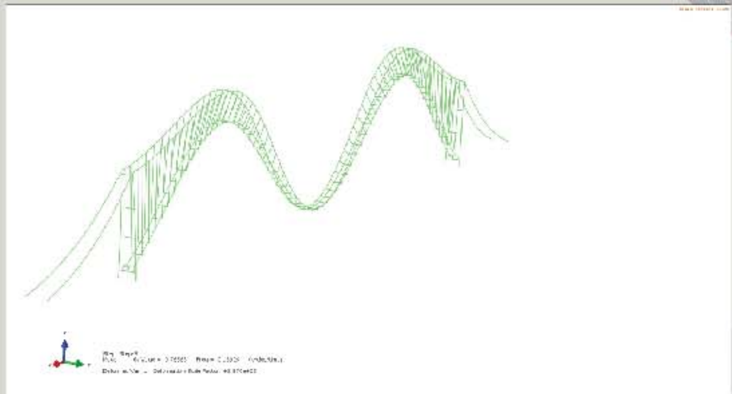
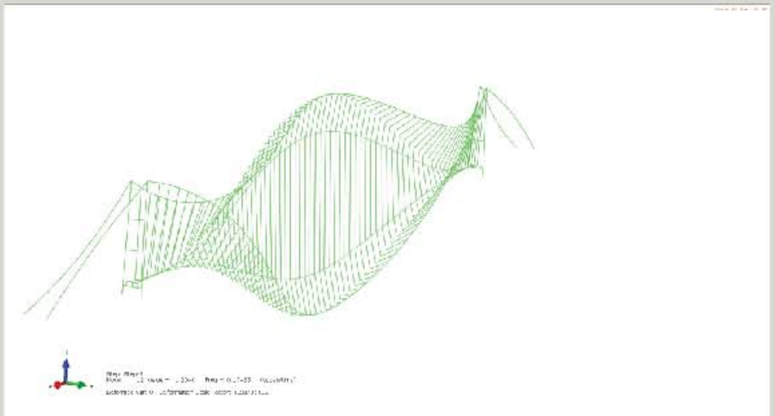


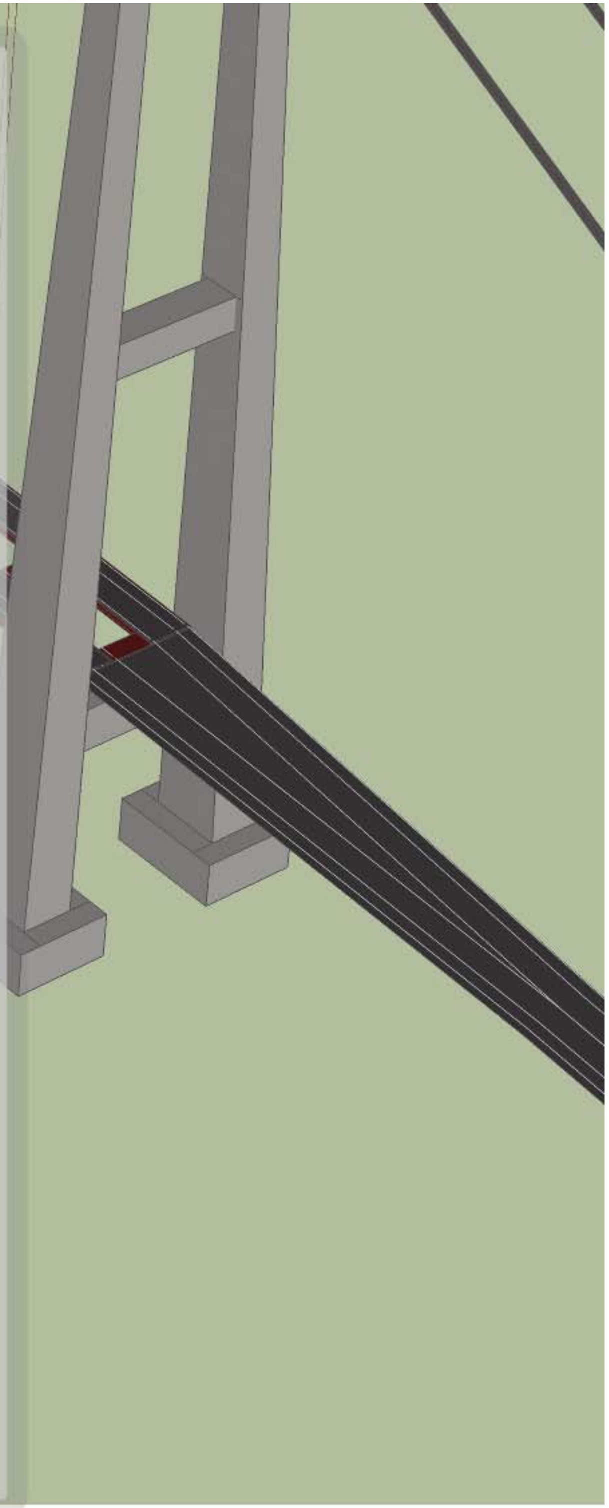




TS1/VS1 = 1.69
Coupling coefficient 0.76

TS1/VS2 = 1.25
Coupling coefficient 0.24





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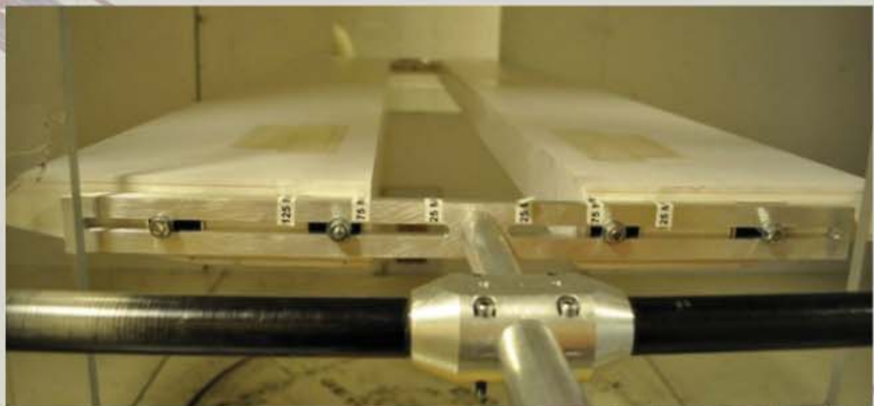

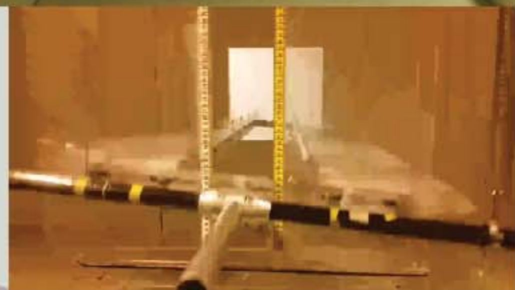

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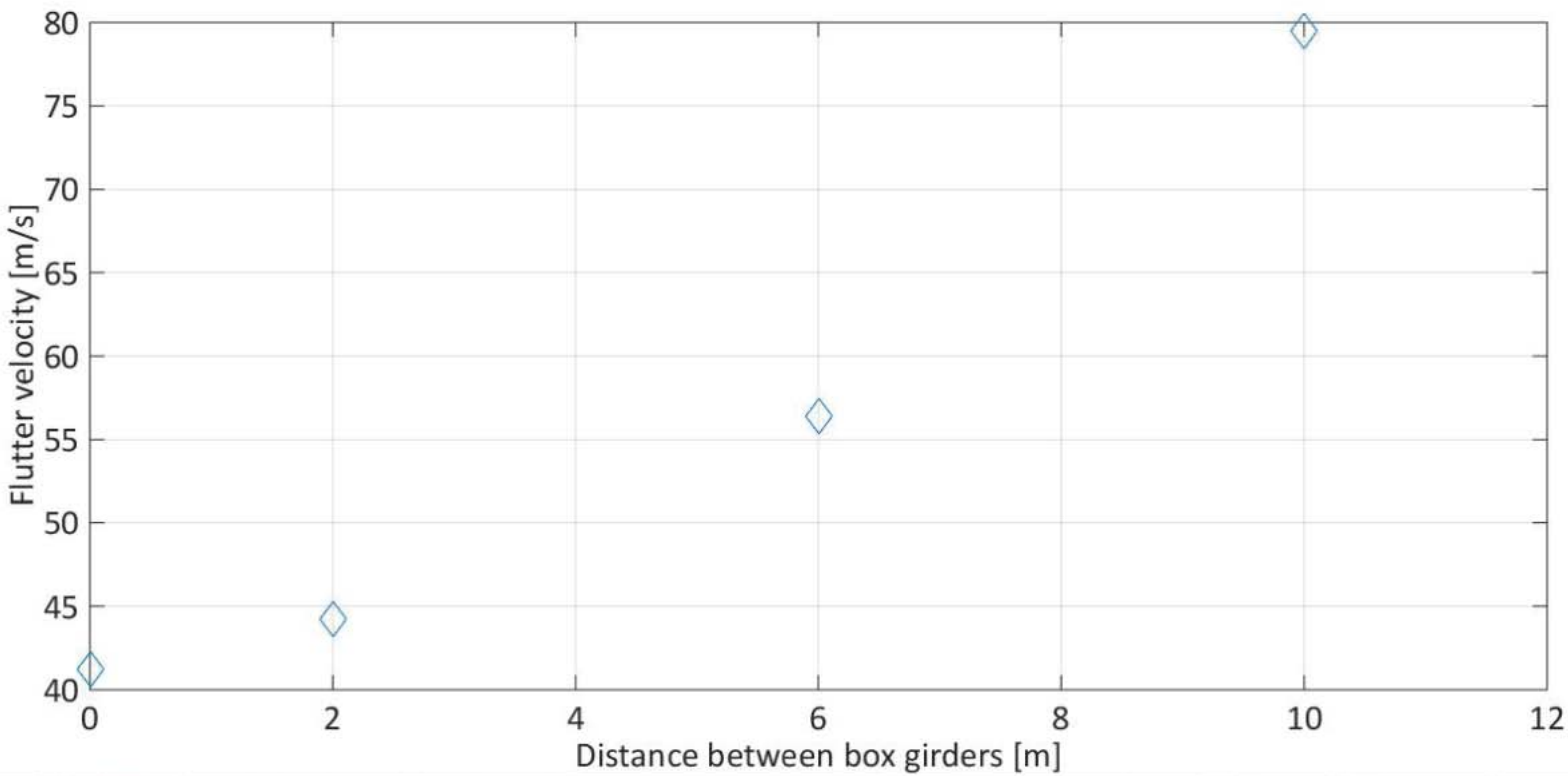
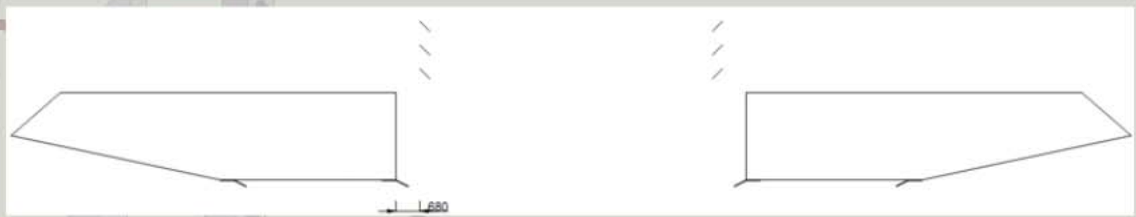


Vortex induced vibrations

- Several configurations to eliminate vortex induced vibrations have been tested
- Vortex mitigation devices reduce the flutter velocity

Config.	Vortex mitigation devices	Wind shield distance	No. wind shield panels	Normalized max. Displacement r/h
V1	None.	None.	None.	0.058
V6	Opposite guide vanes.	680 mm.	3	0.004
V8	Opposite guide vanes on both angles below the bridge decks.	680 mm.	3	0.002
V9	Opposite guide vanes on both angles below the bridge decks.	680 mm.	2	0.006
V10	Opposite guide vanes on both angles below the bridge decks.	680 mm.	1	0.041



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