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Buffeting response predictions of the Hålogaland Bridge based on a data-driven probabilistic description of the wind field

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SUMMARY:
The Hålogaland Bridge, the second longest-span suspension bridge in Norway, was recently instrumented by the Norwegian University of Science and Technology (NTNU) with an extensive monitoring system where wind speeds and global acceleration responses are monitored. In this study, the monitoring data that were recorded in the first two months are used to study the buffeting performance of the bridge under moderate and strong winds. The wind field is modelled using a probabilistic spectral model, the parameters of which are described in terms of joint probability distributions inferred from the measured wind data. The aerodynamic properties of the bridge deck are studied in the wind tunnel, and the structural and modal properties are obtained using a finite element model that is verified using site measurements. The stochastic dynamic response of the bridge is calculated in frequency domain and compared with the measurements. The correspondence of the results is presented and discussed.

Keywords: suspension bridge, buffeting, probabilistic wind field

1. THE HÅLOGALAND BRIDGE AND THE MONITORING SYSTEM

The Hålogaland Bridge (Figure 1) is a long-span suspension bridge in northern Norway, near the city of Narvik. The bridge, which was opened in 2018, remains as of today the second longest-span suspension bridge in Norway with a main span of 1145 meters. The reinforced concrete bridge towers reach around 180 meters from the sea level. The bridge deck is a classical single-deck streamlined steel box-girder, which is 18.6 meters wide and 3 meters high. Shortly after the bridge was opened, it was instrumented by an extensive monitoring system by NTNU (Figure 1), consisting of 22 triaxial accelerometers, of which 16 were installed inside the girder, 4 on the main cables, and 2 in the towers. The wind is measured by 10 anemometers installed on the hangers. A more detailed description of the monitoring system is given in (Petersen et al., 2021). The system collects data continuously since 2022, where the data used in this study covers a period of approximately two months.

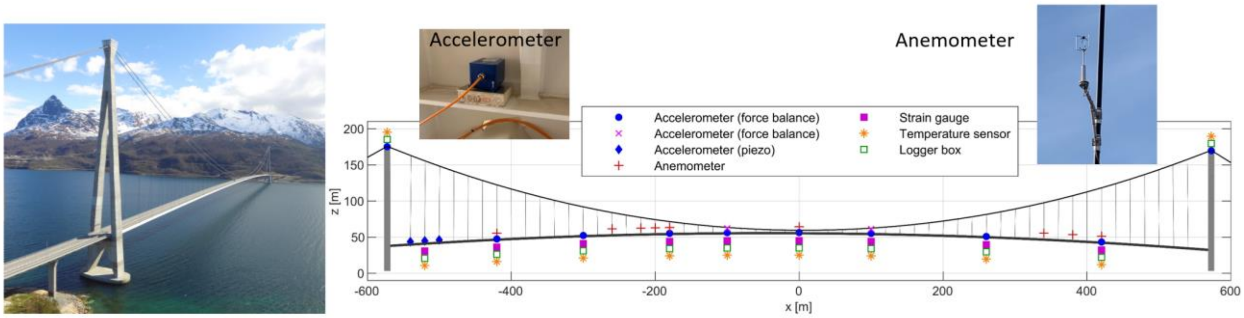

Figure 1. The Hålogaland Bridge (left) and the monitoring system (right), adopted from (Petersen et al., 2021)

2. NUMERICAL MODEL AND OPERATIONAL MODAL ANALYSIS

A finite element model of the bridge was created in the finite element (FE) platform ABAQUS. This model was used to obtain the still-air vibration frequencies and mode shapes of the bridge by solving the undamped eigenvalue problem. To verify the numerical modal properties, the frequencies and mode shapes of the bridge were also identified using covariance-driven stochastic subspace identification (cov-SSI) implemented in the Python KOMA package (Kvåle, 2022). All 16 accelerometers at the deck level were used in the identification. A comparison of the frequencies for the first few vibration modes are given in Table 1. Excellent agreement between the model and identification is observed.

Table 1. First few vibration frequencies of the Hålogaland Bridge: numerical model vs. cov-SSI

mode no.	dominant motion	f_{OMA}	f_{model}	mode no.	dominant motion	f_{OMA}	f_{model}
1	Lateral	0.055	0.054	7	Lateral	0.24	0.23
2	Lateral	0.12	0.12	8	Vertical	0.29	0.29
3	Vertical	0.12	0.12	9	Vertical	0.36	0.35
4	Vertical	0.15	0.14	10	Lateral	0.41	0.4
5	Vertical	0.21	0.21	11	Vertical	0.43	0.42
6	Vertical	0.22	0.22	12	Torsional	0.45	0.44

3. PROBABILISTIC WIND FIELD MODEL

Two months of continuous data were processed and analysed to extract the wind and turbulence characteristics. The measured wind data at the midspan are divided into 10 minute averaging intervals and transformed to the mean and turbulence components, using the procedures described in (Fenerci and Øiseth, 2018). Recordings with a mean wind speed smaller than 3 m/s were discarded as they are hardly meaningful for studying wind-induced dynamics. The mean wind speed and the turbulence intensities are presented for all recordings in Figure 2. It was then assumed that the wind field could be reasonably modelled as stationary and homogenous using the following Kaimal-type model, also used earlier by (Fenerci and Øiseth, 2018), where the auto-spectral densities of turbulence components $S_{\{u,w\}}$ and the normalised cross-spectra $C_{\{u,w\}}(f,\Delta x)$ can be modelled as:

$$\frac{S_{\{u,w\}} f}{\sigma^2_{\{u,w\}}} = \frac{A_{\{u,w\}} f_z}{\left(1+1.5A_{\{u,w\}} f_z\right)^{5/3}}, \; f_z = \frac{f.z}{V}, \; C_{\{u,w\}}(f,\Delta x) = \exp\left(-K_{\{u,w\}} \frac{f\Delta x}{V}\right) \quad (1)$$

where $\sigma_{\{u,w\}}, A_{\{u,w\}}, K_{\{u,w\}}$ are the turbulence parameters. The standard deviations for the along-wind (u) and the vertical (w) components are modelled as log-normally distributed conditional on the mean wind speed whereas other parameters are modelled deterministically, as they are of secondary importance in response predictions. The fitting of the model is done using procedures described in (Fenerci and Øiseth, 2018), and the resulting model is presented in Table 2.

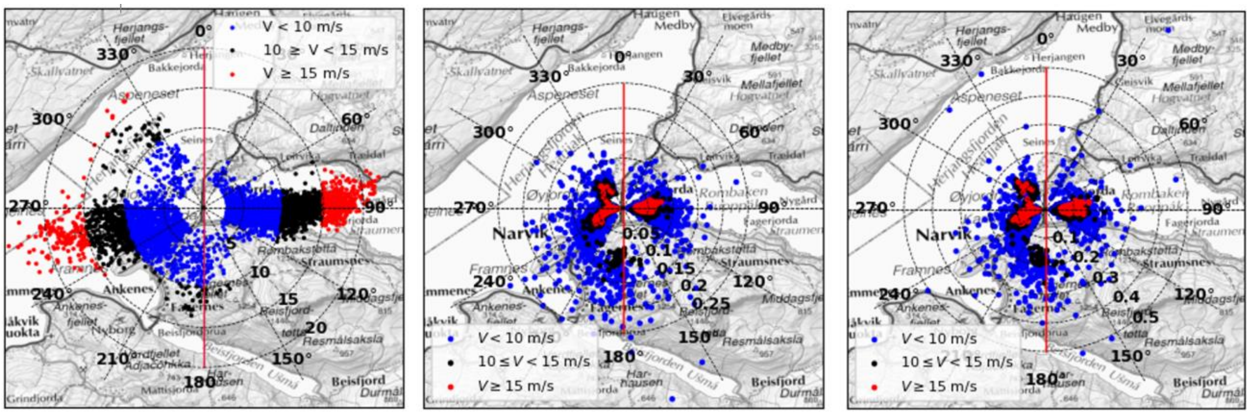

Figure 2. Wind rose scatter plots of mean wind velocity (left), vertical turbulence intensity (middle) and along-wind turbulence intensity (right)

Table 2. Lognormal distribution parameters and correlation coefficients for the probabilistic model of the turbulence standard deviations

	East			West		
	$\tilde{\mu}$	$\tilde{\sigma}$	ρ	$\tilde{\mu}$	$\tilde{\sigma}$	ρ
σ_u	-0.889+0.0705V	0.3211	0.8713	-0.685+0.0446V	0.4324	0.9268
σ_w	-1.155+0.0419V	0.2481		-0.982+0.0214V	0.4604	

4. BUFFETING RESPONSE: MEASUREMENTS VS. PREDICTIONS

The stochastic dynamic response of the deck was calculated in the frequency domain using the multimode method, as described in (Solstad and Onstad, 2022). The aerodynamic properties of the section, namely the static load coefficients and the aerodynamic derivatives, were obtained through forced vibration section model tests in the NTNU wind tunnel (Solstad and Onstad, 2022). By using the probabilistic description given in Section 3, the wind field parameters were Monte Carlo simulated to capture the randomness in the measurements (Table 3). Finally, the root-mean-square (RMS) acceleration responses at the midspan were calculated for comparisons with the field measurements. The resulting RMS acceleration responses for the lateral, vertical, and torsional components are compared with measurements in Figure 3. In general, a good agreement is observed except for the torsional response, where the response generally is overpredicted by the numerical model. Inaccuracies of the aerodynamic properties and the FE-model are considered as part of the explanation for this discrepancy.

Table 3. Wind field model parameters used in response predictions

	V	σ_u	σ_w	A_u	A_w	K_u	K_w
East	from data	Table 2	Table 2	13.9	1.7	7.8	8.9
West	from data	Table 2	Table 2	9.4	1.8	7.8	8.9

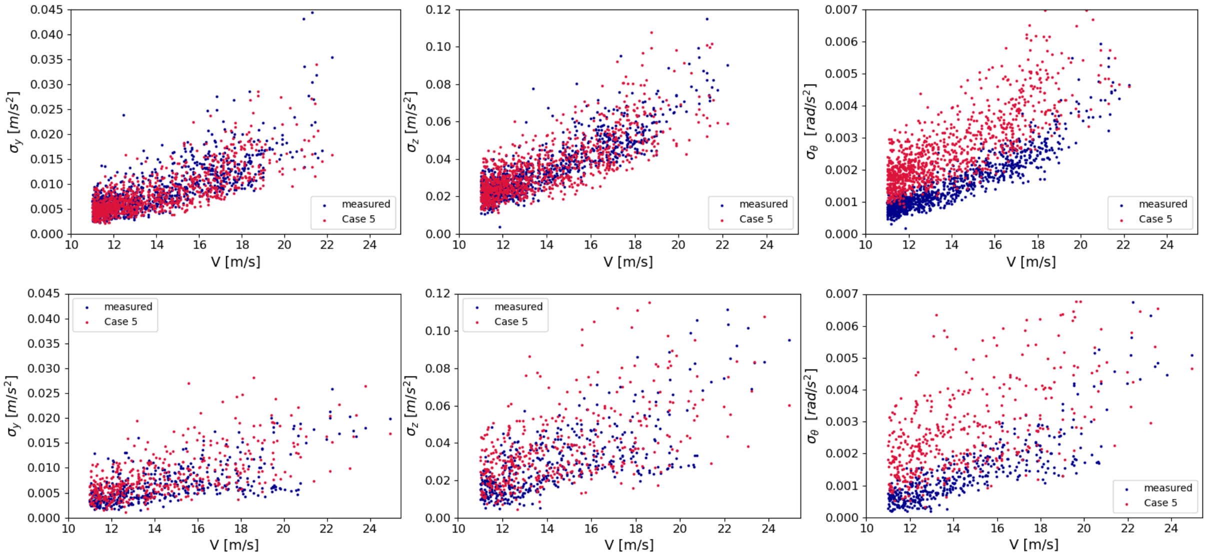

Figure 3. Comparison of the measured and predicted RMS responses plotted against the mean wind speed. Top row: easterly winds, bottom row: westerly winds

5. CONCLUSIONS

The buffeting response of the Hålogaland Suspension Bridge in Norway is studied using both field measurements and analytical predictions. The wind field at the site was modelled considering uncertainty in the turbulence parameters observed in measurement data. The still-air modal properties were estimated using a numerical model and verified by operational modal analysis. The aerodynamic properties were obtained experimentally in the wind tunnel. The predicted responses were then compared to measured responses. In general, a good agreement is observed. Most of the scatter in the data is attributed to uncertain conditions and modelled well using a probabilistic description. Slight discrepancies are found in the torsional response, which should be further investigated.

ACKNOWLEDGEMENTS

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