ICWE 16
August 27-31, 2023
FLORENCE - ITALY
16th International
Conference on
Wind Engineering

A field study of gusts critical to vehicle stability on bridges

Sebastian Reymert[1], Ole Øiseth[1], Øyvind Wiig Petersen[1], Anders Rönnquist[1]

[1]*Norwegian University of Science and Technology (NTNU), Trondheim, Norway,*
sebastian.reymert@ntnu.no

SUMMARY:
To protect road bridge users from wind-related traffic incidents, it is important to characterise the wind environment in which they operate. The summary findings of 11 field sessions are presented in this work to give a more complete picture of the crosswind threats posed to individual vehicle-driver systems when they traverse bridges. A test vehicle was repeatedly driven along segments of 3 fixed-base roads, 4 suspension bridges, 2 beam bridges and 1 cable-stayed bridge under strong crosswinds. Measurements of wind, position, speed, acceleration, and rate of rotation were taken. Discrete obstructions to the wind such as towers and substantial substructure elements were found to affect the driver-perceived stability/controllability of the vehicle along with continuous perturbations resulting from complex upstream terrain and the local separation of flow over the deeper segments of certain girders. Other observed perturbations that are less critical to stability – but important to comfort – include the step change in wind speed at the abutments, the resonant response to vortex streets in the interacting wakes of tower column pairs as well as the turbulent wakes of suspension main cables.

Keywords: Bridge, Topography, Vehicle

1. INTRODUCTION

Wind-related traffic incidents are a regular occurrence on Norwegian road bridges. The current risk management system is primarily based on experience and manual evaluations (Reymert, 2023). There is a need for a better understanding of the characteristics of the wind environment in the space above traffic lanes on road bridges. These characteristics then need to be linked to an understanding of the threats posed to the occupants of vehicles. The aim of this work - through observation in the field - is to paint an overall picture of the wind-related threats to vehicle-driver stability on crosswind-exposed road bridges.

2. METHOD

A Volkswagen (VW) Crafter L4H3 van (see Figure 2a) was used as the test vehicle and is equipped with a Racelogic VBOX 3i data acquisition system. The VBOX system includes dual antenna Global Navigation Satellite System (GNSS) positioning and speed estimation, an Inertial Measurement Unit (IMU) and an 3-axis ultrasonic anemometer. The vehicle was taken to 11 locations in Norway (see map in Figure 1) and repeatedly driven along defined segments of road. Three of said segments are land-based, whereas the remaining segments feature various bridges. The bridges have been drawn and labelled in Figure 1.

Local inhomogeneities in the wind field and the consequences for vehicle-driver response can be identified and characterised by plotting wind and vehicle response data along a spatial axis X_b aligned with each bridge. The wind speed is measured on the moving vehicle. The vector that would be observed by a stationary observer has been calculated by compensating for the GNSS estimated driving speed to give the magnitude V_w that is plotted along with the lateral acceleration A_y in Figure 2b. Both signals have been low-pass filtered with a 7th-order Butterworth filter with a cut-off frequency of 5 Hz. The peak minus the minimum value within a 2-second sliding window is calculated to give gust and response amplitudes ΔA_y and ΔV_w that further highlight the relationship between gusts and handling response. Magnitudes of ΔA_y and A_y have been linked to driver perceptions of wind-induced loss of stability and controllability in (Brandt et al., 2020) and (MacAdam et al., 1990) respectively. A useful reference point from this latter work is that a peak $A_y = 1.35$ m/s^2 can be described as 4/10 uncontrollable (where 10 is total loss of control).

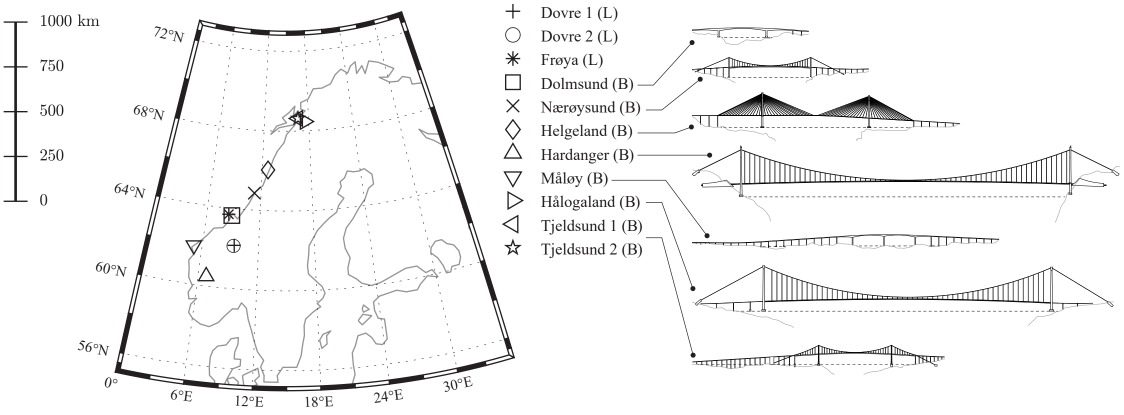
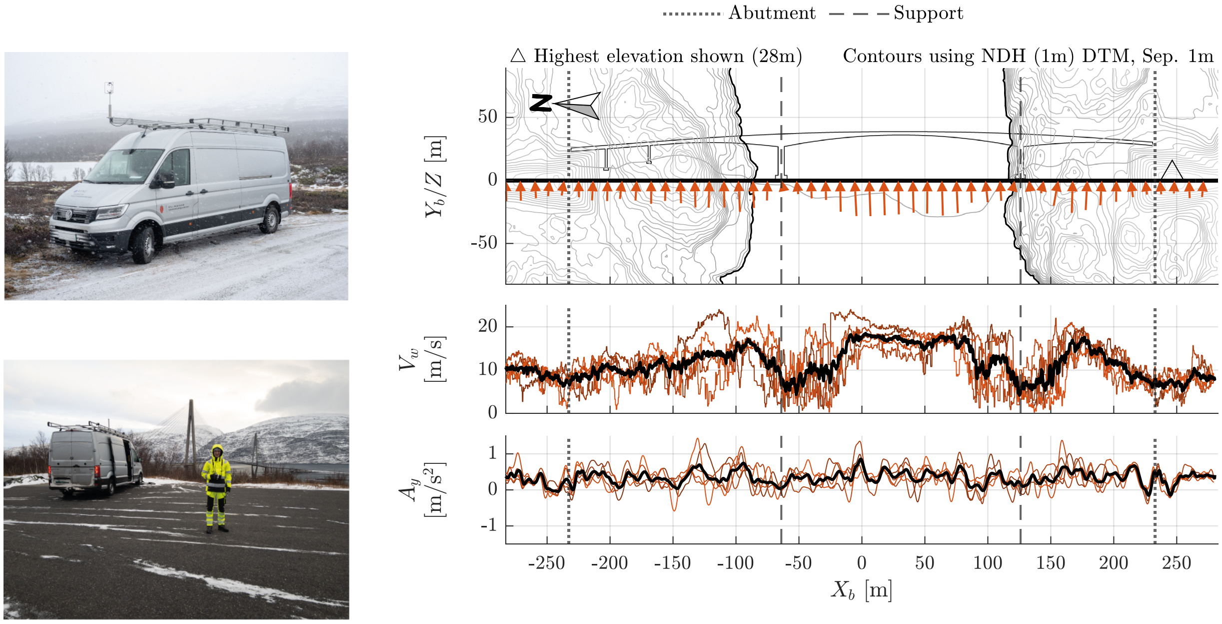


Figure 1. An overview of the sites visited during the field sessions with sketches of the bridges. *L* denotes a land-based road segment and *B* denotes a bridge. There were two sessions at Dovre and the Tjeldsund bridge.

3. RESULTS

Figure 3 includes illustrations of the various phenomena that were identified to perturb the vehicle-driver handling system. The leftmost features are most critical and have been observed to exceed the 4/10 uncontrollable response rating. Such high responses are associated with gust amplitudes higher than 7 m/s. Front axle skid incidents were observed on the Dolmsund and Hardanger bridges in response to wind perturbations. The likelihood of these incidents is increased at these locations due to the thicker girder sections near the piers of the Dolmsund bridge (see Figure 2b) and the complex terrain upstream of the Hardanger bridge. Easterly winds have previously been noted to carry a high turbulence intensity here (Fenerci et al., 2017). The percentage of gust amplitudes above 7 m/s at the Hålogaland bridge - a suspension bridge very similar in span and girder section to the Hardanger bridge - was found to be a mere 1% in the leeward lane. By contrast, this metric is 6% in the leeward lane at the Hardanger bridge and a very significant 73% on the Dolmsund bridge. The increase in turbulence intensity is clear to see in the wind speed signal near the support piers of the Dolmsund bridge in Figure 2b (see $-100 < x < 0$ and $25 < x < 175$).

The highest values of ΔA_y were found in response to the *inverse* gust profile that results from



(a) The test vehicle - a Volkswagen Crafter L4H3 - in the field on the Dovre mountain pass (top) and the Helgeland bridge (bottom).

(b) A demonstration of how map data (©Kartverket), construction drawings and measurements of position, wind and acceleration can be used to identify gusts critical to vehicle safety. Here showing 5 repetitions of driving in the leeward lane on the Dolmsund bridge from right to left on the page at a cruise control speed of 70 kph.

Figure 2. The test vehicle in the field and an example of the resulting data.

passing through the wakes of towers ($\Delta A_y < 4.5$ m/s^2 which approaches the 8/10 uncontrollable rating obtained by (MacAdam et al., 1990)). Nonetheless, no front axle skid event - nor any other distinct traffic incident - was observed in response. This may be because the perturbation is expected by the driver - who in this case was well practiced in the act of passing through such wakes. Large substructure elements, such a piers or counterweights like that drawn in Figure 3b (found at the Tjeldsund bridge) are observed to obstruct the flow above the traffic lane to a similar degree as the towers. The difference is that these perturbations are unexpected and may therefore be perceived as more significant than the towers.

Unexpectedly, a vortex shedding phenomenon was observed at the Helgeland bridge as sketched in Figure 3f. It was observed to oscillate with a frequency between 1.0 and 1.4 Hz in a flow with a mean incident wind speed of 27 m/s. The Reynold's number and Strouhal number have been estimated to be 1.1×10^7 and between 0.23 and 0.30 respectively. The resulting aerodynamic roll moment acting on the vehicle was observed to resonate with the roll mode of the suspension ($f_n = 1.22$ Hz) creating a significant comfort issue.

4. CONCLUSIONS

A substantial and varied data set has been collected to describe the wind environment and vehicle-driver response on road bridges in Norway. The biggest risks to traffic arise from the wakes of bridge towers, substantially obstructive bridge substructure elements, the change in turbulent characteristics resulting from varying girder section thickness (typically on beam bridges) and particularly intense turbulence in regions of complex terrain.

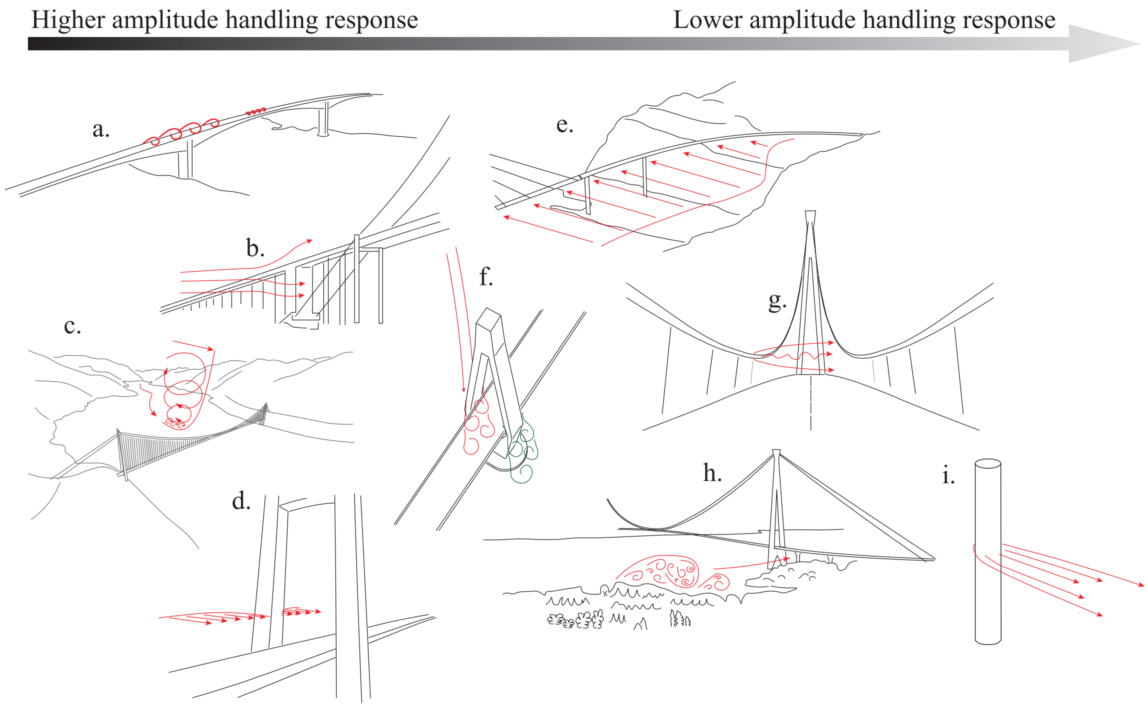


Figure 3. An overview of wind-induced sources of perturbation observed during the field sessions.

(a.) local changes in turbulence characteristics with changing girder section (Dolmsund bridge is drawn) (b.) the shielding effect of a large substructure element under the western approach span of the Tjeldsund bridge (c.) increased turbulence intensity due to complex upstream terrain at the Hardanger bridge (d.) the shielding effect of the Hardanger bridge tower (e.) the step change in wind speed at the northern abutment of the Helgeland bridge (f.) a vortex street in the wake of the towers at the Helgeland bridge (g.) the turbulent wake of the main suspension cable of the Hålogaland bridge (h.) a local increase in turbulence intensity caused by local, complex and rough upstream terrain (i.) the shielding effect of hangers

ACKNOWLEDGEMENTS

This work has been funded by the Norwegian Public Roads Administration (NPRA, or SVV in Norwegian).

REFERENCES

Brandt, A., Sebben, S., Jacobson, B., Preihs, E., and Johansson, I., Apr. 2020. Quantitative High Speed Stability Assessment of a Sports Utility Vehicle and Classification of Wind Gust Profiles. Proceedings of SAE Technical Paper Series. SAE International.

Fenerci, A., Øiseth, O., and Rønnquist, A., Sept. 2017. Long-term monitoring of wind field characteristics and dynamic response of a long-span suspension bridge in complex terrain. Engineering Structures 147, 269–284.

MacAdam, C. C., Sayers, M. W., Pointer, J. D., and Gleason, M., Jan. 1990. Crosswind Sensitivity of Passenger Cars and the Influence of Chassis and Aerodynamic Properties on Driver Preferences. Vehicle System Dynamics 19, 201–236.

Reymert, S., 2023. Field investigations of crosswinds and vehicle-driver response on bridges. PhD dissertation, Norwegian University of Science and Technology.