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Wind actions on Gjemnessund Bridge in full scale and model scale

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SUMMARY:
Norwegian Public Roads Administration initiated a full-scale measurement campaign on Gjemnessund Suspension Bridge to support the ferry free E39 project and development of the E39 coastal highway route in Norway. The main objectives of the measurement campaign were to increase understanding of wind tunnel tests and calculation procedures for prediction of full-scale wind actions on long-span bridges. A monitoring system was developed to measure wind flow properties, wind-induced surface pressures around the bridge deck, and bridge deck acceleration response. Alongside the full-scale measurement campaign, a scale 1:40 section model of Gjemnessund Bridge was tested in the wind tunnel of SOH Wind Engineering LLC, resembling the pressure tap locations in full scale. The dynamic and static Strouhal numbers, vortex-shedding response, and static load coefficients for a range of Reynolds numbers spanning from approx. 10^3 to 10^5 in model scale and beyond 10^6 in full scale are paid attention to. These results may be used for discussion and evaluation of common procedures to perform wind tunnel tests on streamlined bridge decks.

Keywords: Reynolds number effects on vortex-induced vibrations, full-scale measurements, wind tunnel tests

1. INTRODUCTION

Vortex-induced vibrations (VIV) of bridge decks are oscillatory motion caused by vortices shedding from the structure in the presence of a fluid flow such as wind. This phenomenon may cause discomfort to pedestrians and drivers on the bridge. In severe cases vortex-induced vibrations may cause fatigue and damage to the bridge.

Reynolds number is a dimensionless parameter giving the ratio of inertial forces to viscous forces in the fluid flow. At high Reynolds number viscous effects tend to operate on smaller length scales than inertia effects. Amplitude and onset wind speed of vortex-induced vibrations are known to be dependent of Reynolds number as well as static load coefficients on circular structures. On the other hand, sharp-edged structures are less affected by the Reynolds number due to the well-defined separation points at the sharp edges, if the Reynolds number is above 4000.

Several aerodynamic streamlined bridge decks with sharp-edged corners have recently been tested in the wind tunnel of Svend Ole Hansen ApS and SOH Wind Engineering LLC (Hansen et al., 2015). These tests show a Reynolds number dependence of the Strouhal number, vortex-shedding response, and the static load coefficients being similar to what circular cylinders may experience. In particular, the Strouhal number estimated for a vibrating section model is found to deviate from one estimated in a nominally motionless setup.

Norwegian Public Roads Administration initiated a full-scale measurement campaign on Gjemnessund Suspension Bridge in the period 2018-2021 The suspension bridge has a main span of 623 m. The main objectives of the measurement campaign were to increase the understanding of wind tunnel tests and calculation procedures to estimate full-scale wind actions on long-span bridges. This measurement campaign has produced a large database of full-scale measurements, i.e. bridge deck response, wind flow properties, and associated wind-induced surface pressures on the box girder.

A scale 1:40 section model of the box girder was constructed and tested in the wind tunnel of SOH Wind Engineering LLC. Measurements of forces, surface pressures, and wake measurements were carried out to estimate wind action parameters related to vortex shedding and static load coefficients for a wide range of Reynolds numbers.

The dynamic and static Strouhal numbers, vortex-shedding response, and static load coefficients for a range of Reynolds numbers spanning from approx. 10^3 to 10^5 in model scale and beyond 10^6 in full scale are paid attention to. The results going to be presented may be used for discussion and evaluation of common procedures to perform wind tunnel tests on streamlined bridge decks.

2. MONITORING SYSTEM ON GJEMNESSUND BRIDGE

The monitoring system is developed to measure wind flow properties, wind-induced surface pressures around the bridge deck, and bridge deck acceleration response.

The flow properties were measured using three cup anemometers, 15 3D ultrasonic anemometers, and two turbulence probes. The equipment was installed upstream and downstream of the bridge deck to measure the incoming undisturbed wind flow and downstream effects from the bridge deck, i.e. near wake. Anemometers were installed at the bridge deck level and in the main cables.

A total of 190 pressure taps split between six cross-sectional strips located in a span-wise length section of approx. 85 m were installed on the bridge, covering all six deck surfaces. The surface pressures on the bridge girder were measured in six cross-sectional surface pressure strips. The abbreviations *pta*, *ptb*, *ptc*, *ptd*, *pte*, and *ptf* are used for the respective strips, where *pta* is the strip closest to the southern pylon. Each surface pressure strip has either 31 or 32 pressure taps, leaving a single channel available for each of the two static probes. The pressure tap locations are shown in Fig. 1.

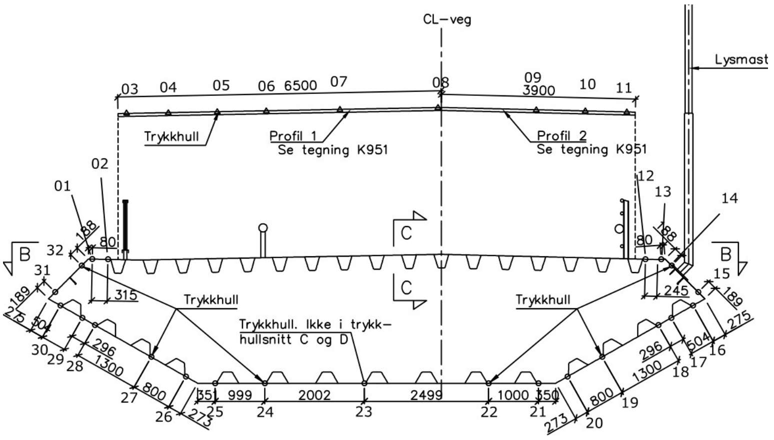

Figure 1. Cross section of the bridge girder and surface pressure tap locations shown by numbers from 01 to 32.

26 accelerometers and one inclinometer were installed to measure the vertical, torsional, and transverse acceleration response of the bridge at several locations along the bridge span. The accelerometers were installed on both sides of the bridge deck cross section and in the cables.

The span-wise location of the ultrasonic anemometers, surface pressure strips, and accelerometers are given in Table 1, and the location of the six surface pressure strips are visually shown in Fig. 2. In Table 1, the parameter x denotes the distance from the southern pylon while z denotes the vertical distance from sea.

Table 1. Location of surface pressure strips in full scale.

Strips	x [m]	Sonic	Location	x [m]	z [m]	Accelerometers	Location	x [m]	z [m]
pta	156.5	*son01*	Pylon top	0	113	*acc01*	Pylon top	0	106
ptb	170.6	*son02*	Main cable	63.5	87.7	*acc02*/*acc03*	In bridge	0	38.0
ptc	193.2	*son03*	Main cable	124.0	72.1	*acc04*/*acc05*	In bridge	63.3	41.0
ptd	201.3	*son04*/*son05*	Deck level	123.4	45.7	*acc06*	Cable	63.4	86.0
pte	235.4	*son06*/*son07*	Deck level	154.8	46.9	*acc07*/*acc08*	In bridge	123.8	43.9
ptf	241.4	*son08*/*son09*	Deck level	183.9	47.9	*acc09*	Cable	123.9	71.3
		son10	Main cable	184.5	60.8	*acc10*	Cable	184.4	60.1
		son11/*son12*	Deck level	200.0	48.2	*acc11*/*acc12*	In bridge	184.3	46.1
		son13/*son14*	Deck level	208.1	48.5	*acc13*/*acc14*	In bridge	244.8	47.9
		son15	Deck level	498.8	45.7	*acc15*/*acc16*	In bridge	311.5	47.9
						acc17/*acc18*	In bridge	377.9	47.4
						acc19/*acc20*	In bridge	438.4	46.1
						acc21/*acc22*	In bridge	498.9	43.9
						acc23/*acc24*	In bridge	559.4	41.0
						acc25/*acc26*	In bridge	623	38.0

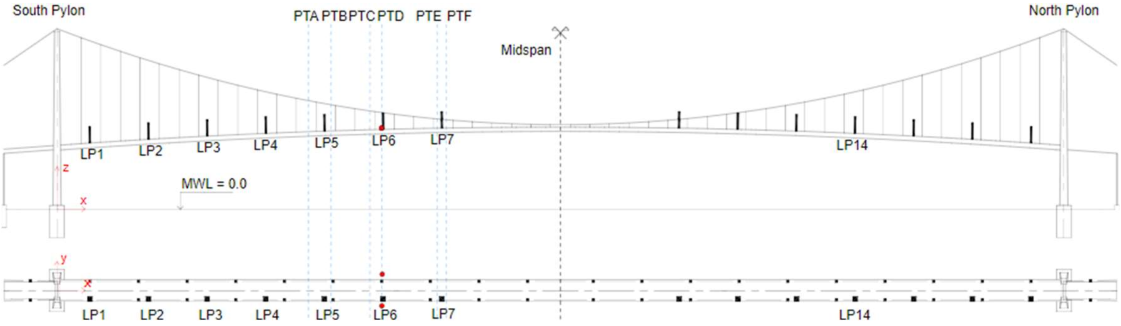

Figure 2. Location of surface pressure strips on the full-scale bridge.

A detailed description of the monitoring system used in the full-scale measurement campaign on the Gjemnessund Bridge may be seen in the paper (Andersen et al., 2021).

The pressure taps on the section model are located at the same positions compared to the full-scale bridge girder.

3. RESULTS

The paper pays attention to the topics described below and presents results of the related analyses:

- Full-scale structural damping level of Gjemnessund Bridge compared to other suspension bridges.
- Dynamic and static Strouhal number as function of Reynolds number estimated from surface pressure measurements and wake measurements, in both model scale and full scale.
- Displacements due to vortex shedding in full scale and model scale as function of Reynolds number.
- Drag force, lift force, and moment coefficients as function of Reynolds number using full scale and model scale surface pressure measurements.

The results are inviting to a discussion and evaluation of common procedures to perform wind tunnel investigations for streamlined bridge decks. Considerations of aspect ratio, blockage ratio, Reynolds number, and scaling will be included in the paper, information which may be relevant for future section model investigations in wind tunnel.

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REFERENCES

Hansen, S. O., Srouji, R. G., Isaksen, B., and Berntsen, K., 2015. Vortex-induced vibrations of streamlined single box girder bridge decks. In: Proc. of 9th National Symposium on Wind Engineering, ICWE14, Jun 21-26, Porto Alegre, Brazil.

Andersen, M. S., Hansen, S. O., Isaksen, B., 2021. Full-Scale Monitoring of the Wind Field, Surface Pressures and Structural Response of Gjemnessund Suspension Bridge. Structural Engineering International, Special issue on the Dynamics and Aerodynamics of Slender Structures, February 2022.