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# An overview of the Julsundet Bridge aerodynamic design

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**SUMMARY:**
The design of the Julsundet Bridge, included in the E39 fjord crossing project in Norway, is affected by both the complex wind scenario induced by the local terrain and the aerodynamic properties of the deck. Specifically, the relevant fjords that characterize the Norwegian coastline could induce strong modification in the incoming wind impacting the bridge's dynamic response. Additionally, the 1625m span covered with a single-box deck section makes the critical flutter speed close to the design value. In this context, an experimental campaign was carried out in the Politecnico di Milano wind tunnel to properly address both issues. A 1:1000 scale terrain model is used to investigate the expected wind field at the bridge site while a deck sectional model suspended on springs is employed to check the aeroelastic stability. In this abstract, the experimental tests are described and a preliminary set of results is presented.

*Keywords: wind tunnel tests, topographic effects, flutter instability, super long-span bridges, bridge aeroelasticity*

## 1. INTRODUCTION

Wind-induced effects play a key role in the design of long-span bridges (Argentini et al., 2022). Investigating those effects implies accounting for both the aerodynamic properties of the deck itself and the wind conditions expected at the bridge site. The latter may become particularly critical in case the site is characterized by hilly regions that make the prediction of the topography-induced effects not straightforward.

The Julsundent Bridge project is a typical example where both aspects are important. Specifically, the wind scenario is strongly influenced by the complex fjords that distinguish the country's coastline, while the significant span combined with the single-box deck section makes the aeroelastic design of the bridge particularly challenging. This deck solution has already been used effectively for shorter suspension bridges, e.g. the Hardanger Bridge or the Humber Bridge. Nevertheless, increasing the length of the main span, the flutter speed decreases and, for the Julsundet Bridge, we are close to the value that allows the applicability of this solution ($V_{crit} = 65.6 m/s$, computed as reported by Vegnormal N400 Bruprosjektering, clause 5.6.8-1, 2023). This aspect may be further worsened by the complex wind conditions induced by the fjords. This is the main reason why, in recent years, information about terrain-induced effects has been incorporated into bridge design through large measurement campaigns (Castellon et al., 2022). However, if such information is somehow incomplete due to the installation of the sensors (usually on land and far from the bridge) (Fenerci et al., 2023), they can be supplemented by topographic tests performed through wind tunnel tests or numerical simulations (Lystad et al., 2018).

Hence, to properly cover the aerodynamic design of the Julsundet Bridge, an experimental campaign was conducted in the Politecnico di Milano Wind Tunnel, addressing both the terrain effects and the investigation of the aerodynamic properties of the deck section. In the present abstract, after briefly presenting the experimental setup for both test types, some relevant results are reported and commented on.

## 2. METHODOLOGY

### 2.1. Topographic Study

To have an accurate description of the wind field, a dedicated topographic study has been performed in the boundary layer test section of the Politecnico di Milano Wind Tunnel, as depicted in Figure 1; a 10 km diameter surround area is reproduced, assuming a length scale of 1:1000, allowing a proper representation of the elevations closest to the site of the Julsundet bridge. During the experimental tests, 16 different incoming wind directions are considered. The wind directions include those perpendicular and parallel to the bridge axis and 10, 20, 30 and 45 degrees yawed to the normal axis in northwest, southwest and southeast sectors. Among others, the most interesting outputs for design purposes are the mean angle of attack over the deck axis (at 76.52m from water level) for stability issues and the lateral scales of the wind. For the towers (271m high), the flow field over the tower development can be measured, allowing the investigation of the buffeting response of such structures.

**Figure 1.** The terrain model in the wind tunnel test section

### 2.2. Evaluation of deck aeroelastic stability

Different deck configurations have been tested in the high-speed test section of Politecnico di Milano wind tunnel using a suspended sectional model, as shown in Figure 2. The main purpose is to investigate the aerodynamic stability of the bridge changing small details while keeping constant the deck shape. Therefore, different sets of barriers, railings and gantry rails were tested. For the sake of brevity, a limited set of configurations is here presented. Specifically, the baseline configuration ("JUL-R0", see Figure 3 without modelled snow) and the bare deck ("JUL-B", see Figure 3 without any fitting) will be considered. Moreover, the impact of the snow on the deck aerodynamics is investigated ("JUL-S", see Figure 3).

## 3. RESULTS AND DISCUSSION

### 3.1. Topographic study

As an example of the results, Figure 4 shows flow measures along the deck axis, for two different incoming wind directions. Specifically, the first subplot shows the magnitude of the velocity vector normalized to the reference velocity measured by a Pitot tube placed at the beginning of the turning table at tower height. The second and third subplots report yaw and pitch angles

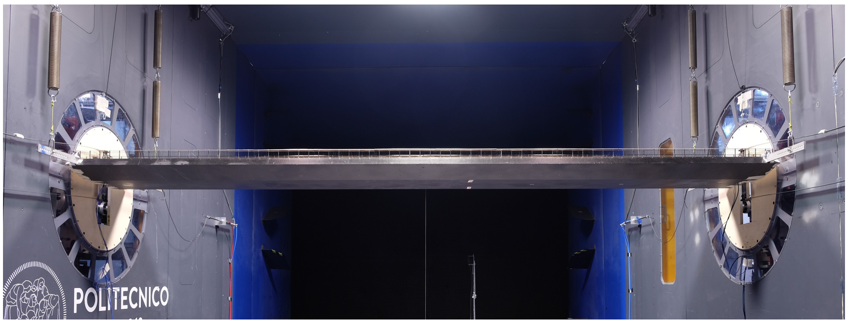


**Figure 2.** Julsundet Bridge deck sectional model suspended on springs

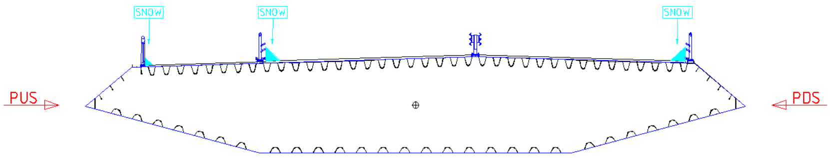


**Figure 3.** Sketch of the Julsundet Bridge deck sectional model. The fittings representing the snow accumulation at the roadside are also reported. Both wind directions were investigated (PUS=Pedestrian UpStream, PDS=Pedestrian DownStream)

defined with respect to the inlet wind. Yaw angle is in the horizontal plane and it is positive when we have a counterclockwise rotation; pitch angle is in the vertical plane and it is positive if upward. For wind direction normal to the deck axis (blue markers), the flow is subjected to a slight acceleration resulting in normalized velocities over 1 along the deck axis. The mean angle of attack (pitch angle) is null, except for the closest location to the Nautneset tower, where it reaches -5°. Considering instead the wind direction 302° (red markers in Figure 4), the effects due to the fjords result in a drop of the mean wind speed, due to the sheltering effects on the Nautenest side, and in a flow deviation, as highlighted by a -25° yaw angle.

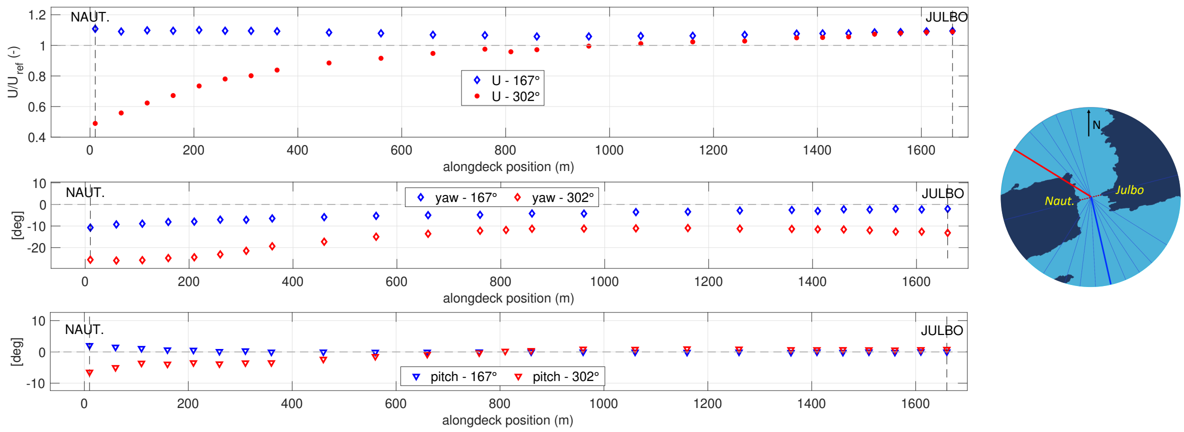


**Figure 4.** Results from velocity measurements along the deck axis. Incoming wind directions are depicted in the right figure.

### 3.2. Stability Investigation

In this section, a selection of results related to the investigation of the deck stability is presented. Figure 5(a) illustrates the damping ratio as a function of the full-scale mean wind speed, considering the "PUS" wind direction (refer to Figure 3). A deck static angle of rotation equal to 0° is selected since, as shown in Figure 4, when the wind direction is perpendicular to the bridge, the angle of attack approaches 0° across almost the entire span. For all the selected configurations, the flutter speed is greater than $70m/s$. On the other hand, considering the "PDS" wind direction, the stability of the deck is strongly affected by the presence of the snow positioned at the roadside (see Figure 5(b)). The presence of the snow could induce the detachment of eddies from the section, strongly modifying its aeroelastic behavior. This hypothesis is also confirmed by Figure 6, showing the $a_2^*$ coefficients expressed according to Zasso, 1996. Specifically, the negative values related to the "JUL-S" configuration represent a negative torsional aerodynamic damping and thus, an eventual 1-dof torsional instability. As for the other configurations, the adopted deck solution can be considered aerodynamically robust. In the extended version of the paper, a more complete set of results will be presented.

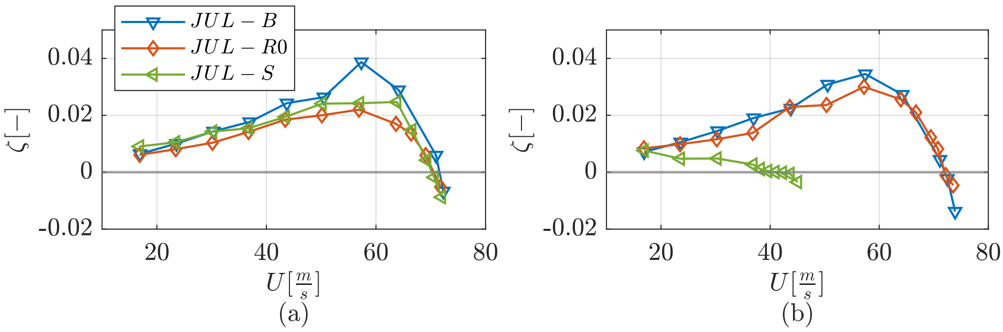


**Figure 5.** Damping ratio as a function of the full-scale mean wind speed. Figure (a) shows the results related to the "PUS" wind direction while, Figure (b), those related to the "PDS" wind direction. In both cases, the deck angle of rotation is set equal to 0°

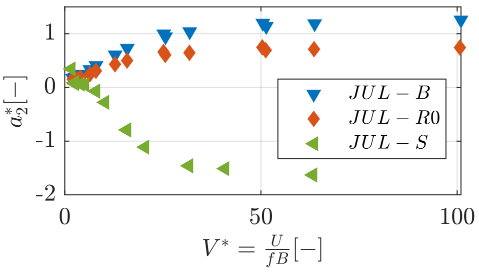


**Figure 6.** $a_2^*$ coefficient as a function of the reduced velocity $V^*$ (defined as the ratio between the mead wind speed $U$ and $fB$, where $f$ is the frequency of oscillation of the imposed torsional motion and $B$=27.5m is the deck chord) for the different configurations, related to the "PDS" wind direction and a deck angle of rotation equal to 0°.

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