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ERIES-DisDeck: Flutter Mitigation with Distortionable Bridge Decks

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SUMMARY:
One of the main challenges in long-span bridge design is assessing aeroelastic stability under dynamic wind loading. Advances in materials and structural engineering have enabled increasingly slender and lightweight decks. However, their greater span and flexibility make them more vulnerable to buffeting and flutter, which remain key limitations in the design process.
This research proposes a novel flutter-mitigation concept for twin-box bridge decks that introduces a controlled cross-sectional deformation through a bar-and-spring system, adding an extra degree of freedom – i.e. distortion – to the conventional heave and pitch motions, resulting in an increase of the critical wind speed.
The paper presents the experimental campaign conducted in the Giovanni Solari Wind Tunnel at the University of Genoa within the EU Project ERIES. The tests aim to characterize the aeroelastic behavior of distortion-capable twin-box decks across a range flow velocities and to extract flutter derivatives to validate a parallel numerical study.

Keywords: Flexible cross-section, Flutter mitigation, Wind tunnel test.

1. INTRODUCTION

When dealing with wind effects mitigation on bridges engineers can adopt several strategies including increasing structural stiffness, enhancing damping or modifying the deck geometry to alter the airflow. Increasing stiffness is generally impractical for long-span bridges due to the associated rise in cost and structural mass. Additional damping can be introduced through tuned mass dampers (TMDs), which are effective for mitigating vortex-induced vibrations (VIV) but less suitable for flutter (Chen and Kareem, 2003), since VIV occur at the natural frequency of the structure while flutter can develop over a broader frequency range governed by aeroelastic forces. Consequently, geometrical modifications are commonly considered the most effective approach for flutter mitigation (Raggett, 2016). These solutions are typically investigated through sectional and full-scale wind tunnel tests, where different geometric variations are assessed. Although effective, this process is costly and largely case-specific, requiring dedicated experimental campaigns for each bridge design.
To overcome these limitations, recent research has explored the use of movable aerodynamic devices, such as winglets attached to the deck edges, which can significantly influence the flow field and be adapted to different geometries. Some studies have proposed actively controlled devices operated through electronic systems (Bakis et al., 2016; Kobayashi and Nagaoka, 1992), while others have introduced passive solutions mechanically coupled to the deck

motion (Omenzetter et al., 2000; Wilde et al., 1999), allowing the devices to activate automatically as the deck rotates.

The approach proposed in this work within the ERIES Project "DisDeck - Flutter Mitigation with Distortionable Bridge Decks" follows a different concept, that is reducing flutter susceptibility by introducing an additional degree of freedom in the bridge cross-section (Martínez-López et al., 2026). This extra degree of freedom, associated with cross-sectional distortion, does not need to be directly linked to the deck's heave or pitch motion. The cross-sectional distortion is realized by means of a set of springs that connects the two portions of the deck. When properly tuned, the deformation activates naturally under aerodynamic loading, contributing to improved flutter stability.

This study presents the wind tunnel tests carried out in the Giovanni Solari (GS) Wind Tunnel at the University of Genoa, along with some preliminary results, covering both the rigidly connected and fully separated deck configurations. These represent the two limit cases corresponding respectively to springs of infinite stiffness and zero stiffness.

2. EXPERIMENTAL SETUP

The tests are conducted in the Giovanni Solari Wind Tunnel facility at the University of Genoa, a closed-loop facility characterized for its low turbulence levels. The wind tunnel has a rectangular test section, which is 1.7 m wide and 1.35 m high. The controllable wind speed range is between 0.2 m/s - 32 m/s.

The tests are carried out in the first measurement section, located at the inlet of the test chamber, 1.5 m downstream of the convergent. The reference flow velocity inside the tunnel is measured by a Pitot-static tube positioned approximately 20 cm from the roof of the test section, upstream of the model and in a region undisturbed by its presence. The three wind velocity components are additionally measured by means of a TFI Cobra probe, capable of acquiring all three components at a sampling frequency of 2 kHz. Finally, regarding the displacement measurements, the tunnel is equipped with 7 laser sensors that allow to measure plunge, torsion and possibly rocking of the model.

This study employs a twin-deck sectional model (Figure 1) of a bridge where the two decks are connected through a set of springs and hinged rods that allows the cross-sectional distortion of the section. The model is tested in three different configurations: full rigid deck, which assumes the inner springs with infinite stiffness; free deck, which assumes zero stiffness of the inner springs; stiff deck, which includes different configurations of inner springs with six different intermediate values of stiffness k_D. The inner elements used to reproduce these three different set ups are showed in Figure 2. The complete rigid deck is achieved by means of rigid elements clamped on the two decks (Figure 2a) while for the case of free decks, pinned parallel rods are installed, allowing distortion between the two decks (Figure 2b). Finally, for the case of flexible deck different number of pairs of springs with different stiffness are tested, which are installed with a cross shape in the middle of the two decks but forcing the rotation of the individual deck boxes to be the same (Figure 2c). For this case, the bars used for the free decks case (Figure 2b) are still mounted, therefore the rotations of the boxes remain the same.

3. PRELIMINARY RESULTS AND ON-GOING ACTIVITIES

The intended wind tunnel experiments will complement and validate a parallel numerical campaign to extract the flutter derivatives of several distortionable twin-box decks and to study the optimal configuration, i.e. the optimal setup of the springs that allows for the highest critical wind speed for the flutter conditions. In this framework, the benchmark of the tests carried out

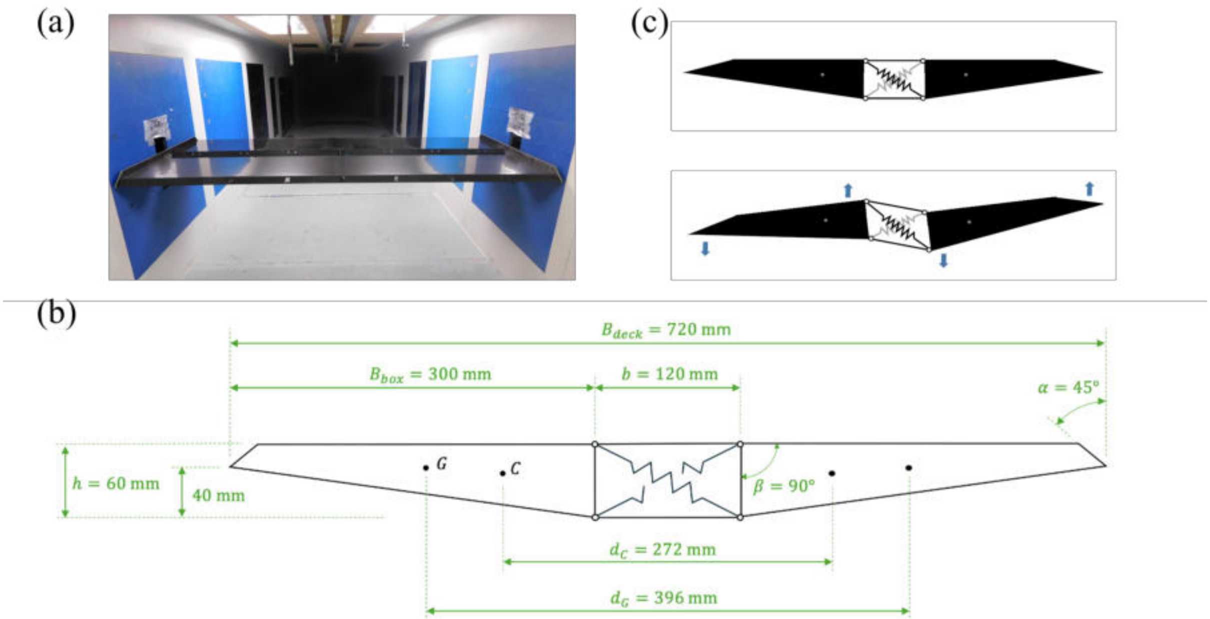

Figure 1. Twin-box deck model: (a) model in the test chamber; (b) geometry dimensions, G center of mass and C center of rotation; (c) distorted configuration of the section (Martínez-López et al., 2026).

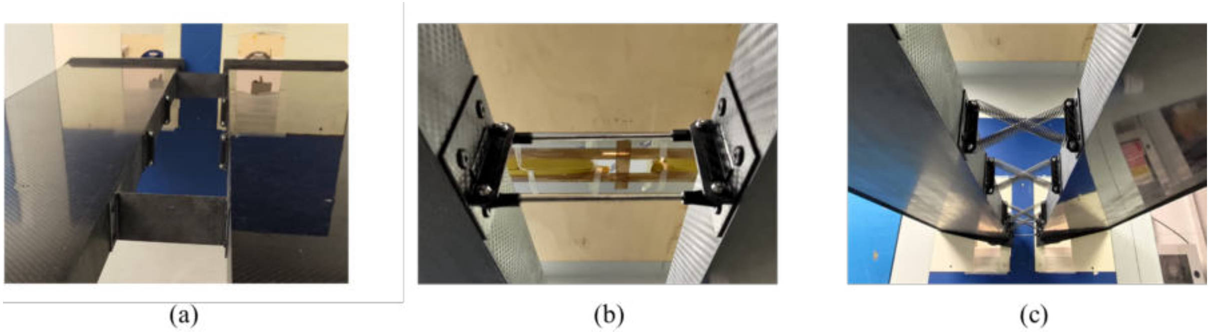

Figure 2. Twin-deck configurations: (a) full rigid deck; (b) free deck; (c) fixed stiffness properties.

the GS-Wind tunnel is represented by the results obtained through CFD analyses of the same twin-box deck configurations, reported in Figure 3. The plot shows the values of the lowest critical wind speed, associated with the three modes – i.e. bending, torsion and distorsion, on varying the stiffness of the inner springs k_D. It is observed that the highest critical wind speed is given for an intermediate value of the stiffness, while lower values of the critical wind speeds are observed for limit cases of the free decks ($k_D = 0$) and full rigid decks ($k_D \to +\infty$). Moreover, the critical wind speed is lower for the rigid deck configuration compared to the free one. Specifically, starting from the case of rigid deck, on reducing k_D classical flutter occurs, with the critical wind speed that increases up to its maximum in correspondence of the peak. On decreasing k_D the dominant mode becomes distortion and the critical wind speed decreases up to the limit case of free decks where $k_D = 0$.

In order to compare these preliminary CFD results with the experimental tests in the wind tunnel, the critical wind speed is estimated per each deck configurations by testing the deck models at different wind speeds up to the instability conditions. Preliminary results obtained for the fully separated and rigidly connected deck configurations, which represent the limiting cases of the curve in Figure 3, show good agreement with the CFD analyses, confirming the

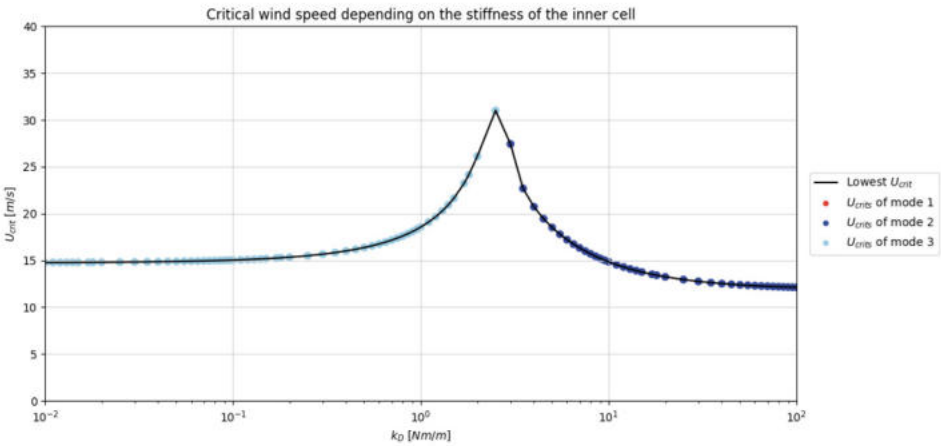

Figure 3. Flutter critical wind speed, obtained from the numerical campaign, on varying the stiffness of the inner springs.

reliability of the experimental setup. The next steps of the campaign involve testing the spring configurations across different numbers and stiffness values, with the aim of capturing the peak observed in Figure 3. Subsequently, the flutter derivatives of the various twin-box deck configurations will be extracted, allowing the evaluation of their influence on the critical wind speed and confirming the findings from the analytical model.

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