Experimental Investigation of Aeroelastic Behavior of a Shallow Π-Shaped Bridge Deck during Construction Stage

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ABSTRACT

In this study, the aeroelastic behavior of a shallow Π-shaped deck section of a long-span cable-supported bridge was experimentally investigated in both completed and construction-stage configurations using an elastically mounted sectional model in a wind tunnel. During the construction stage, the deck functions as a cantilever system with reduced effective stiffness and modified boundary conditions, which can significantly affect its aeroelastic stability. The scaled model was allowed to oscillate in two degrees of freedom, namely vertical translation and torsional rotation. Wind tunnel tests were conducted within a wind velocity range of 3.27 to 7.72 m/s and under various initial angles of attack.The primary objective was to evaluate the influence of structural configuration changes on the static divergence threshold and dynamic oscillation amplitudes. The results indicated that, in the construction-stage condition, static torsional and vertical responses increased by approximately 6% and 10%, respectively, compared with the completed configuration. Furthermore, the dynamic oscillation amplitudes in torsion and vertical motion increased by about 8.5% and 5.5%, respectively. In certain angles of attack, the onset of instability occurred at lower wind velocities during the construction stage, indicating a shift in the aeroelastic stability boundary due to stiffness reduction and altered boundary conditions. The findings demonstrate that direct extrapolation of the completed-state aeroelastic behavior to the construction stage may result in unconservative stability evaluation. Therefore, dedicated aeroelastic modeling is recommended to ensure safe design of long-span bridges during erection stages.

KEYWORDS

Aeroelasticity; Construction stage; Cable-supported bridge; Torsional divergence; Wind tunnel testing

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1. Introduction

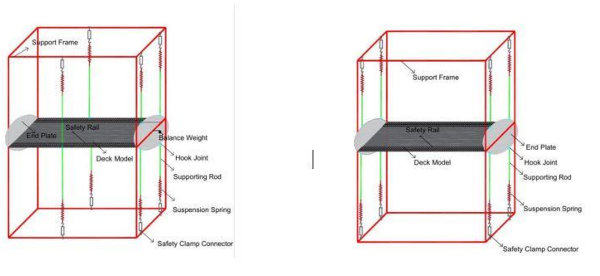
Wind-induced aeroelastic instability is one of the governing design criteria for long-span bridges[1]. Bridge decks with shallow Π-shaped sections are particularly sensitive to aerodynamic excitation due to their geometric characteristics and relatively low torsional stiffness[2]. The aeroelastic response of such decks depends on the interaction between aerodynamic forces, structural stiffness, damping, and boundary conditions[3].Although many studies have investigated the aeroelastic behavior of completed bridges[4], the construction stage has received less attention[5]. During construction, the structural system may experience reduced stiffness, asymmetric support conditions, and temporary mass distribution, which can significantly affect aeroelastic stability[6].

In this study, the aeroelastic behavior of a shallow

Π-section bridge deck is experimentally investigated in a wind tunnel using an elastic sectional model. Two structural states are considered: the complete bridge configuration and the under-construction configuration. The objective is to evaluate how structural changes during construction influence torsional response, vertical response, and oscillation amplitudes under different wind speeds and angles of attack.

2.Experimental Methodology

Wind tunnel tests were conducted using an elastic sectional model representing a shallow Π-section bridge deck. Two structural configurations were examined, as illustrated in Fig1.



a) Under-Construction Deck with Safety rails b) Completed Deck with Safety rails

Figure 1. Elastic sectional model configurations: complete bridge and under-construction bridge.

The experiments were performed at five angles of attack

α= (0°, ±3°, ±6°)

and wind speeds ranging from

U=3.27 m/s to 7.72 m/s

The aerodynamic loading is related to the dynamic pressure

$$q = \frac{1}{2}\rho V^2 \tag{1}$$

where ρ is the air density and V is the wind velocity.

The lift force and pitching moment acting on the bridge deck can be expressed as

$$M = \frac{1}{2}\rho V^2 B^2 C_M \tag{2}$$

$$L = \frac{1}{2}\rho V^2 B^2 C_L \tag{3}$$

where B is the deck width, and C_L and C_M are the lift and pitching moment coefficients.

Assuming linear structural behavior, the static responses are given by

$$h = \frac{1}{2}\frac{\rho V^2 B C_L}{K_h} \tag{4}$$

$$\theta = \frac{1}{2}\frac{\rho V^2 B^2 C_m}{K_\theta} \tag{5}$$

where h is the vertical displacement, θ is the torsional rotation, and K_h and K_θ denote the vertical and torsional stiffness, respectively. The measured responses included torsional rotation, vertical displacement, and oscillation amplitudes in both directions. The overall experimental uncertainty was estimated to be approximately ±3%.

3.Results and Discussion

The aeroelastic responses obtained from the wind tunnel experiments are presented in Fig2 Fig3 and Fig4**.**The comparison of torsional rotations for the two configurations is shown in Fig 5 **.**The results indicate that the under-construction configuration exhibits larger torsional rotations than the complete bridge configuration, particularly at higher wind speeds. This behavior is mainly attributed to the reduction in effective torsional stiffness and the change in boundary conditions during construction**.**

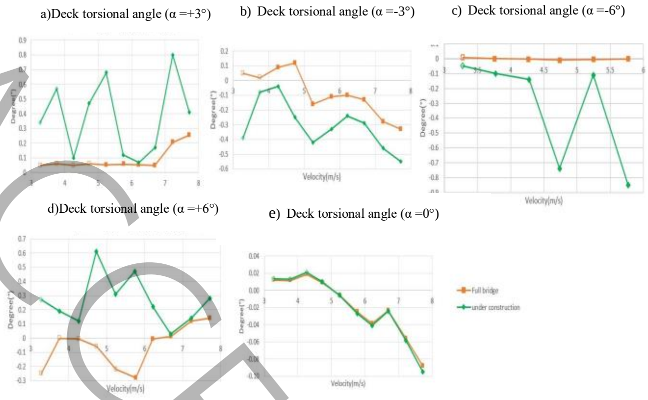


Fig. 2. Comparison of torsional rotation for the two structural configurations.

The vertical displacement results are presented in Fig3 Similar to the torsional response, the under-construction configuration generally shows larger vertical displacements over the tested wind speed range, confirming that the temporary structural system is more susceptible to aerodynamic excitation**.**

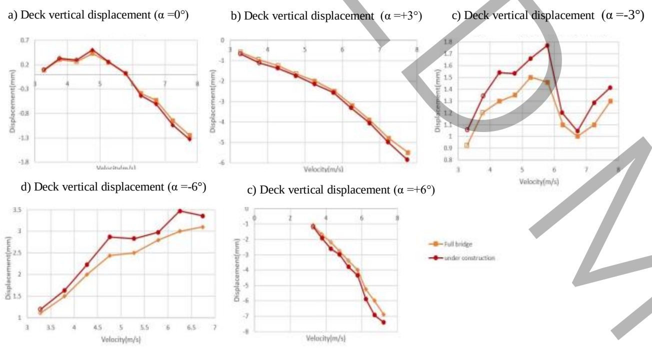


Fig. 3. Comparison of vertical displacement for the two structural configurations.

The torsional oscillation amplitudes are compared in Fig4The experimental results demonstrate that the oscillation amplitude in the under-construction configuration is approximately 8.5% larger than that of the complete bridge configuration. This increase indicates stronger aeroelastic coupling due to reduced stiffness and modified structural constraints.

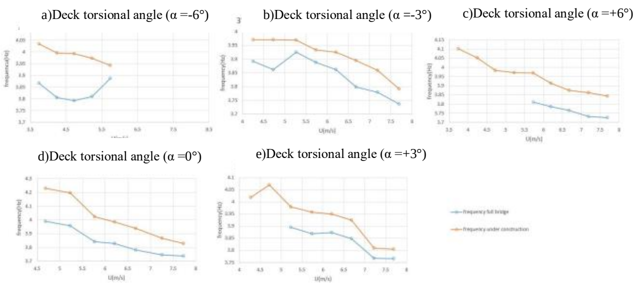


Fig. 4. Comparison of torsional oscillation amplitudes.

The influence of the angle of attack is also significant. Variations in aerodynamic coefficients near the instability region cause noticeable changes in structural response. As wind speed increases, aerodynamic energy transfer to the structure intensifies, leading to a gradual growth in oscillation amplitude and possible development of limit cycle oscillations (LCO). the results highlight that the aeroelastic stability of the bridge deck evolves throughout the construction process. Structural modifications during construction alter stiffness distribution and boundary conditions, thereby shifting the aeroelastic stability boundary**.**

4.Conclusions

This study experimentally investigated the aeroelastic behavior of a shallow Π-section bridge deck in two structural states: the complete bridge configuration and the under-construction configuration.Wind tunnel tests were conducted at five angles of attack (0°, ±3°, ±6°) and wind speeds between 3.27 and 7.72 m/s.The results show that the under-construction configuration exhibits larger aeroelastic responses than the complete bridge. In the static response, torsional rotation and vertical displacement increased by approximately 6% and 10%, respectively. In the dynamic response, torsional and vertical oscillation amplitudes increased by about 8.5% and 5.5%, respectively.In addition, the onset of instability occurred at lower wind speeds in the under-construction configuration, indicating a reduction in the aeroelastic stability margin during construction.Therefore, aeroelastic evaluation should consider multiple structural stages during bridge construction rather than only the final bridge configuration in order to ensure adequate safety against wind-induced instabilities.

5.References

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