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Effects of wind barrier on the wind environment and driving safety of a streamlined bridge deck at non-null attack angles

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SUMMARY:
In this study, the effects of wind barriers on the wind environment of vehicle driving safety on a long-span bridge with a streamlined bridge deck were investigated in smooth flow at different attack angles by wind tunnel test. The results showed that the wind barrier can effectively reduce the mean wind speed above different traffic lanes of the bridge deck, especially for the windward traffic lanes. The increase in the attack angle enhances this inhibition effect and leads to a higher and larger reverse flow region above the bridge deck. Additionally, the wind barrier obviously increases the turbulence intensity above the bridge deck. This enhancement effect weakens as the increased attack angle, especially for leeward traffic lanes. The results also demonstrated that the wind barrier can effectively reduce the equivalent wind speed above the bridge deck and improve the driving safety of vehicles, especially for the windward traffic lanes. Compared with the risk of vehicle sideslip, the effect of the wind barrier on reducing the risk of vehicle overturning is more obvious. It is worth noting that the windproof effect of the wind barrier on the leeward traffic lanes weakens obviously at a larger wind attack angle.

Keywords: wind barrier, wind environment, driving safety, crosswinds, wind tunnel tests

1. INTRODUCTION

To improve the local wind environment and the driving safety of vehicles on a bridge deck, the wind barrier has been widely applied in many prototype bridges, such as the Xihoumen bridge (Yang et al, 2022). There has been a number of research on the impact of wind barriers on the wind environment above and driving safety of a vehicle on bridge decks (Kim et al, 2016; Telenta et al, 2014; Xu and Guo, 2003). However, the investigated attack angle of incoming flow was set to be zero degree in most previous studies. There are limited studies on the effects of wind barriers in the incoming flow with different attack angles. The objective of this paper is to study the effects of the wind barrier on the wind environment and driving safety for a long-span bridge with a streamlined bridge deck at non-null attack angles. The results of this study will contribute to a more thorough understanding of the effects of wind barriers at non-null attack angles.

2. EXPERIMENTAL SETUP

The bridge decks equipped with railings and wind barriers and the diagram of the accessory structures are illustrated in Fig. 1. L1 to L3 denote the first three windward traffic lanes and L4 to L6 denote the fourth to the sixth leeward traffic lanes. It should be noted that the ventilation rates of the railing and wind barrier are 67% and 54%, respectively. The scale ratio of the section model is 1:70. The wind environments above the bridge deck equipped with the railing and wind barriers were measured at a mean wind speed of 11.0 m/s in smooth flow at attack angles of -2.5°, 0° and 2.5°. The fluctuating longitudinal wind speeds were measured by pressure probe sensors and Scanivalve scanners. The sample frequency was 256 Hz and the sample duration was 60 s. To ensure a good frequency response, the system damper was used in the test. The measurement points of wind speeds are located at the centerline of each traffic lane. The heights of the seven measuring points are 0.7 m, 1.33 m, 1.97 m, 2.6 m, 3.23 m, 3.86 m, and 4.5 m above the traffic lanes.

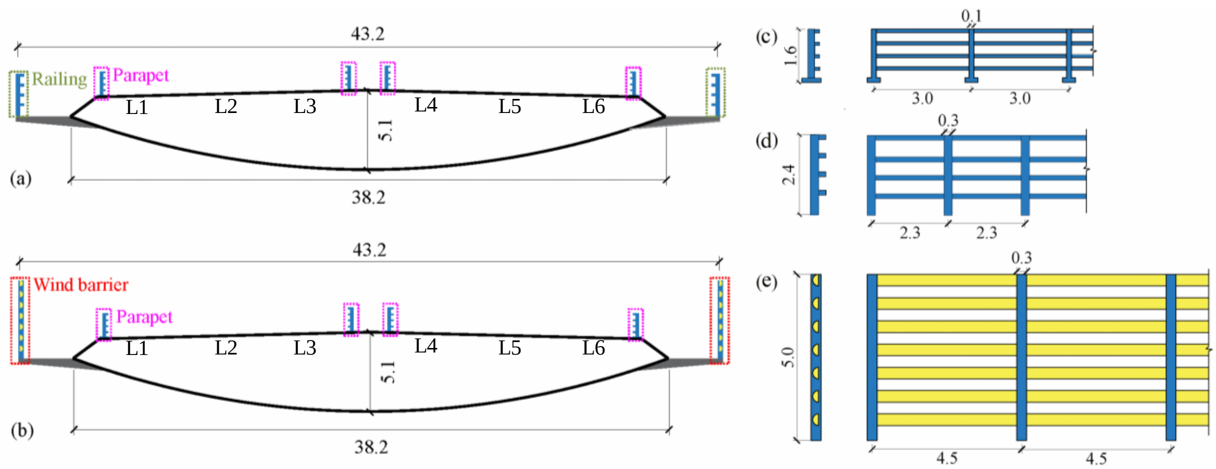
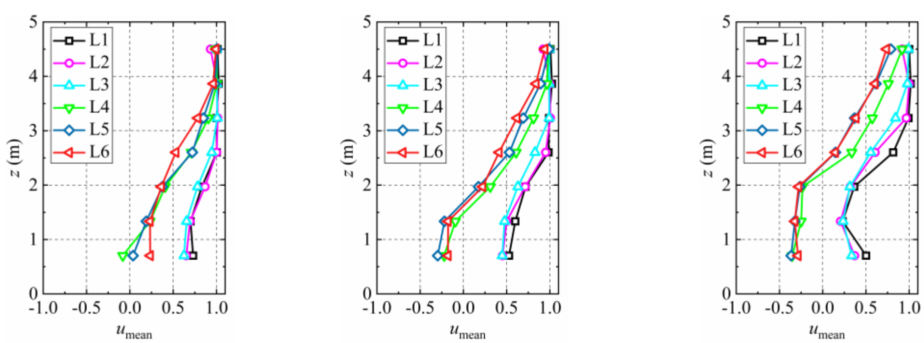


Figure 1. Cross-section of the streamlined bridge deck and schematic diagram of accessory structures. (a) deck with railings; (b) deck with wind barriers; (c) parapet; (d) railing; (e) wind barrier (unit: m).

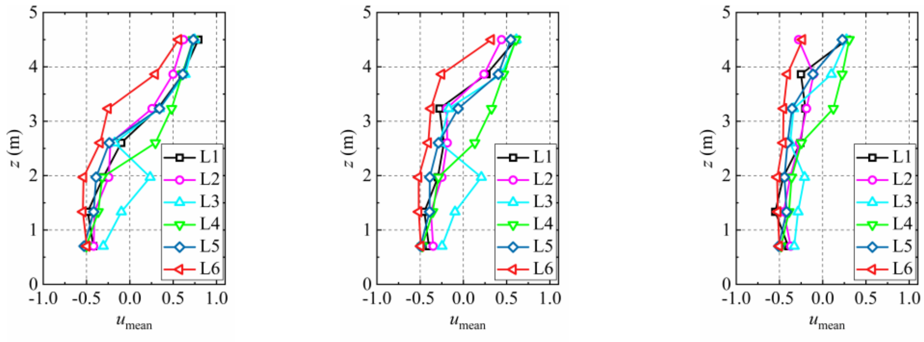
4. MEAN WIND SPEED PROFILE

Fig. 2 shows that the mean wind speeds (u_{mean}) above the bridge deck equipped with wind barriers are reduced obviously compared with the bridge deck equipped with railings. This can be attributable to the larger mean radius of the separation shear layer generated by wind barriers and weaker bleed flows through the wind barriers. It can also be found that the inhibition of wind barriers on the mean wind speed becomes more significant as the increased attack angle.



(a) α = -2.5° (b) α = 0° (c) α = 2.5°

(i) Bridge deck equipped with railings.



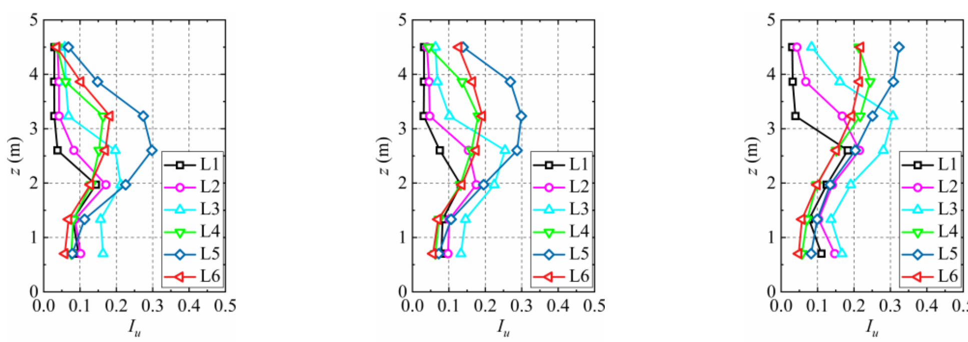
(a) α = -2.5° (b) α = 0° (c) α = 2.5°

(ii) Bridge deck equipped with wind barriers.

Figure 2. Profile of normalized mean wind speed above the bridge deck equipped with railings.

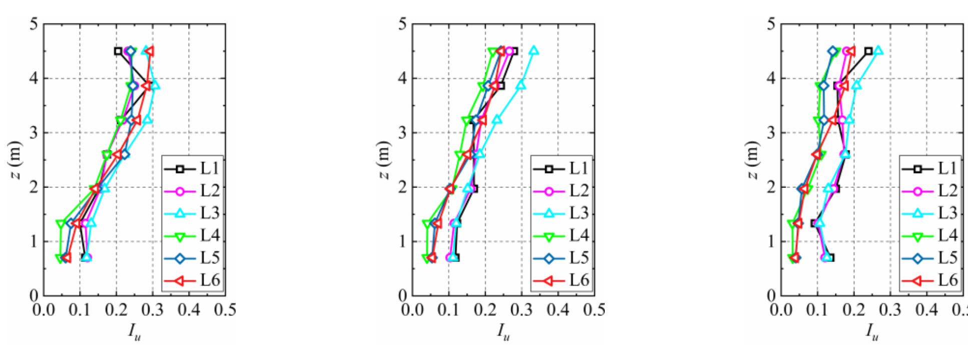
5. TURBULENCE INTENSITY

Fig. 3 shows that the height of the location where the peak turbulence intensity (I_u) occurs raises with the increased attack angle for the bridge deck equipped with railings. The wind barrier enhances the turbulence intensity at the higher region above the bridge deck on the one hand, and increases the height of the position where the peak turbulence intensity appears on the other hand. The increase in the wind attack angle weakens the enhancement effect of wind barriers on the turbulence intensity, especially for the leeward traffic lanes.



(a) α = -2.5° (b) α = 0° (c) α = 2.5°

(i) Bridge deck equipped with railings.



(a) α = -2.5° (b) α = 0° (c) α = 2.5°

(ii) Bridge deck equipped with wind barriers.

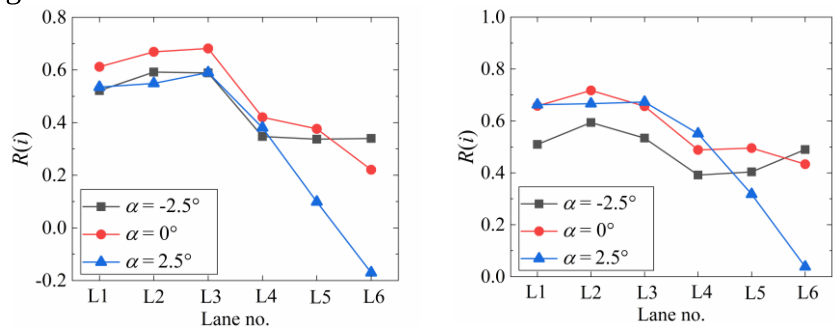
Figure 3. Profile of normalized mean wind speed above the bridge deck equipped with railings.

6. EQUIVALENT WIND SPEED

In order to comprehensively evaluate the windproof performance of wind barriers, the reduction coefficient of equivalent wind speeds is defined as:

$$R(i)=\frac{U_{\text{R-eff}}(i)-U_{\text{B-eff}}(i)}{U_{\text{R-eff}}(i)} \tag{1}$$

where $U_{\text{B-eff}}(i)$ and $U_{\text{R-eff}}(i)$ are the equivalent wind speeds at *i*-th lane of the bridge deck equipped with wind barriers and railings respectively. Fig. 4 shows that the wind barrier can effectively reduce the equivalent wind speeds at different attack angles, especially for the windward traffic lanes. The reduction coefficient calculated based on the overturning moment is much larger than that of lateral force. The reduction coefficient of leeward traffic lanes decreases obviously at a larger attack angle of 2.5°.



(a) Based on lateral force (b) Based on overturning moment

Figure 4. Reduction coefficient above different traffic lanes at different attack angles.

7. CONCLUSIONS

The increase in the attack angle enhances the inhibition effect of wind barriers on mean wind speed above the bridge deck. This also weakens the enhancement effect of wind barriers on turbulence intensity above the bridge deck, especially for the leeward traffic lanes. The wind barrier can effectively improve the wind environment of vehicle driving safety at different attack angles, especially for the windward traffic lanes. However, the windproof effect on the leeward traffic lanes weakens obviously at a larger wind attack angle.

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