Influence of aerodynamic measure on the transient aerodynamic performance of high-speed train passing bridge-tunnel junction under crosswinds

Linbo Tang [1], Xuhui He [1,2,3], Lei Yan [1,2,3]

[1] School of Civil Engineering, Central South University, Changsha 410075, China;
[2]National Engineering Research Center for High-Speed Railway Construction, Changsha 410075, China;
[3]Hunan Provincial Key Laboratory for Disaster Prevention and Mitigation of Rail Transit Engineering Structures, Changsha, 410075

SUMMARY:
In this study, a moving model experiment with three different cases is conducted to research the influence of different tunnel portals and the wind barrier on the transient aerodynamic performance of high-speed train when it passes the bridge-tunnel junction under crosswind. The result shows that the oblique portal can delay the change of the side force coefficient of the train at the tunnel portal but it can not reduce the amplitude of it. On the contrary, the wind barrier is an effective method to reduce the side force coefficient of the train in this scenario. For the selected wind barrier, the maximum amplitude of the pressure coefficient change of taps on section C4 of the train near the portal reduces about 60% to 80% and cause the maximum value of side force coefficient reduces 80%.

Keywords: bridge-tunnel junction, oblique portal, wind barrier

1. INTRODUCTION

Previous studies have found that when the train passes through the bridge-tunnel junction under crosswind, the aerodynamic force will change rapidly, which may affect the safety and stability of the train. Therefore, how to mitigate the change of aerodynamic force has received wide attention. The effects of oblique tunnel portal and wind barrier are discussed in this paper.

2. EXPERIMENTAL SYSTEM

All tests were conducted on a moving model test system in the wind tunnel laboratory of Central South University. As Fig. 1(a) shows, the moving train model is firstly accelerated by a high-speed servo motor and conveyor belt, then come cross the low-speed section of the wind tunnel, which provides a stable flow field for the experimental system, with a nearly constant speed. Finally, it is stopped by rubber strips at the deceleration section out of the wind tunnel. The pitot tubes in front of the bridge are used to measure the crosswind speed and static pressure. The train speeds at specific positions are measured by the photoelectric sensor at the leeward side of the tunnel, as Fig. 1(b) shows. The surface pressure of the car body is measured using a self-developed wireless aerodynamic pressure measurement system (He et al., 2021). As Fig. 1(c) shows, the train model structure is designed with an openable top side, allowing for the wireless pressure measurement system settle on the framework of the moving model. The system comprises the data acquisition box, the reference pressure sealed box, the battery, and the differential pressure transducers. The data acquisition box features a total of 16 channels, offering a sampling frequency range of 0-10 kHz. For this particular experiment, a sampling frequency of 2 kHz is utilized. The differential pressure transducers have a measurement range of ±2 kPa, with a testing accuracy of 0.5%.

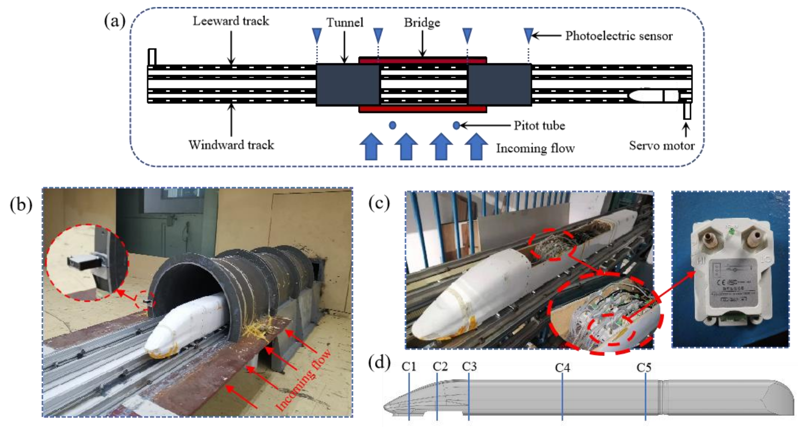

Figure 1. Wireless pressure measurement system. (a) Plan view of measurement system. (b) Arrangement of photoelectric sensors and pitot tube. (c) Arrangement of differential pressure transducers. (d) Arrangement of measured section

In this experiment, A basic case with normal portal and without wind barriers, a case with oblique portal and without wind barriers and a case with normal portal and wind barriers were considered, as shown in Fig. 2. They are named as Case 1 to Case 3. The test model is a 1:16.8 CR high-speed train. Five cross sections are measured, which is named C1 to C5, as Fig. 1(d). The bridge model is a standard high-speed railway simply-supported beam, and the tunnel structure is a standard double-track railway tunnel with a cross-sectional area of 100 m^2 (Tang et al., 2023). The total length of the tunnels on both sides is 3 m. The oblique portal is 1m long. The wind barrier is 0.208m high, 4m long and its porosity is 30%.

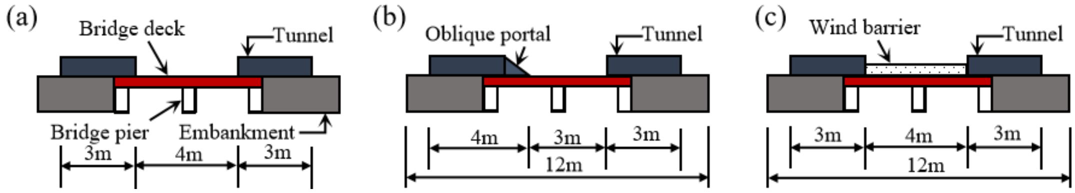

Figure 2. Three conducted cases. (a) Case 1 (Normal portal without wind barrier). (b) Case 2 (Oblique portal without wind barrier). (c) Case 3 (Normal portal with wind barrier)

3. EXPERIMENTAL RESULT

The experiment result is presented in a non-dimension form, side force coefficients and pressure coefficients, which are defined as Eq. (1) and Eq. (2).

$$C_s = \frac{F_s}{0.5\rho U^2 hl} \quad (1)$$
$$C_p = \frac{P-P_0}{0.5\rho U^2} \quad (2)$$

where C_s, C_p denote the side force coefficient and pressure coefficient, respectively; F_s represents the side force; ρ is the air density; U is the incoming wind speed; h is the height of the measured section; l is the length of the measured section, regarded as unit length, 1m. P is the pressure of the measuring taps; and P_0 is the reference pressure of the wind tunnel.

Fig. 3 shows the side force coefficients of the train measured section under the cases 1 to 3. It can be seen that the oblique portal has no obvious influence on the side force coefficient of the train, but it can delay the change of it. It is notable that the side force coefficient of section C1 change a little on the bridge part compared with that of the normal portal. When the train exit the portals, the increasement of side force coefficient of Case 1 occur twice while that of Case 2 occur once. It indicates the oblique portal makes the flow field transition between tunnel and bridge smoother. On contrast, it is obvious that the wind barrier can significantly reduce the side force coefficient.

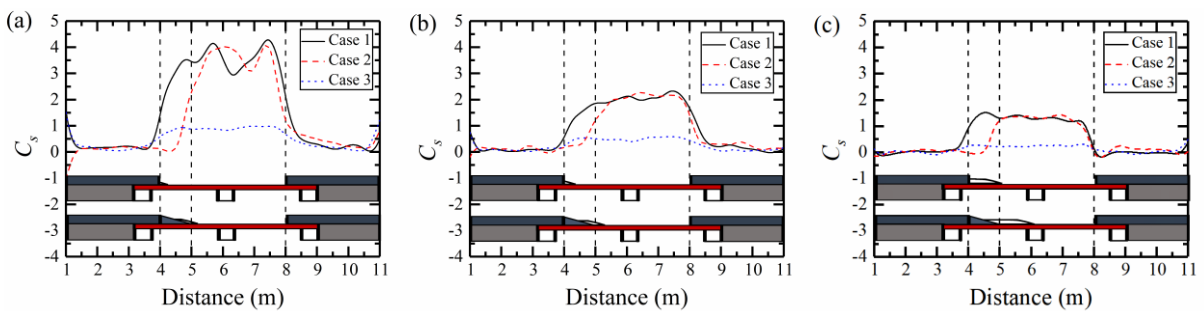

Figure 3. Side force coefficients of train cross sections under different conditions. (a) C1 section. (b) C2 section. (c) C4 section.

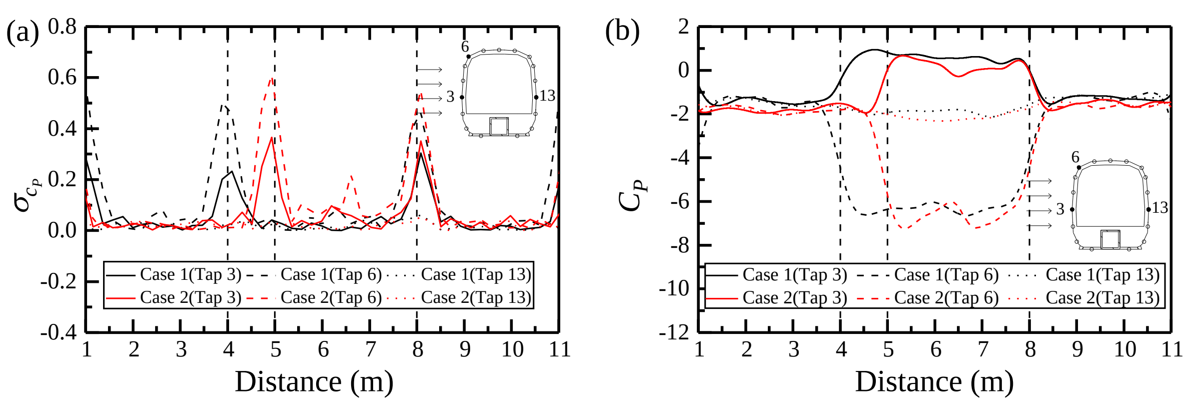

Figure 4. Pressure coefficients of measurement taps and standard deviation of them under Case 1 & 2. (a) Standard deviation of pressure coefficients of measurement taps. (b) Mean pressure coefficients of measurement taps.

Fig. 4 shows the variation of train surface pressure coefficients of section C4 with different tunnel portals. It can be seen from Fig. 4(a) that for both cases, the pressure coefficients change on the windward side of the train is significantly greater than that on the leeward side. Especially near the portal. However, it is worth noting that the standard deviation varies more in case 2, but that of train entering the portal is nearly the same. For both cases, the second tunnel portal is a normal one, so the oblique portal makes the pressure coefficient change rate increase when the train exit the portal. According to Fig. 4(b), for the measurement point on the windward side, the maximum pressure coefficients after exiting the portal is not much different in both cases, but inside the portal, the pressure coefficients of case 2 will increase firstly, then decrease and finally increase to the maximum value. For the measurement point on the top and leeward side, the maximum negative value in case 2 is larger than that of case 1. Hence the standard deviation of pressure coefficients in case 2 are larger than that of case 1.

Fig. 5 shows the variation of train surface pressure coefficients of section C4 with and without a wind barrier. Obviously, under the shielding effect of the wind barrier, the pressure coefficients change at each measuring point of the train is significantly reduced. The maximum amplitude of the pressure coefficient change near the portal reduces about 60% to 80%. Therefore, the aerodynamic force of the train is significantly reduced.

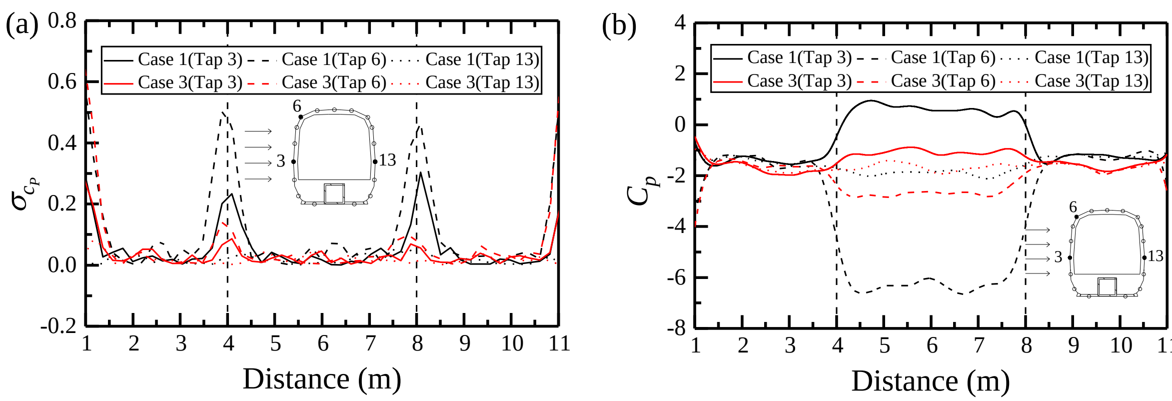

Figure 5. Pressure coefficients of measurement taps and standard deviation of them under Case 1 & 3. (a) Standard deviation of pressure coefficients of measurement taps. (b) Mean pressure coefficients of measurement taps.

4. CONCLUSIONS

The results show that the oblique portal has little effect on the side force coefficient amplitude of the train exiting the tunnel, but can delay the change of side force coefficient. The wind barrier can significantly reduce the side force coefficient amplitude and change intensity of the train at the portals.

ACKNOWLEDGEMENTS

This paper is supported by National Natural Science Foundation of China (Project 51925808, 52178516), Any opinions and concluding remarks presented in this paper are entirely those of the authors.

REFERENCES

He, X. H., Zou S. M., 2021. Advances in wind tunnel experimental investigations of train–bridge systems. Tunnelling and Underground Space Technology 118, 104157.

Tang, L. B., He, X. H., Yan, L., and Lin, Z., 2023. Experimental study of aerodynamic characteristics of high-speed train on bridge-tunnel junctions under crosswinds. Journal of Central South University, 30(2), 613-624.