Influence of Wind-Break Wall on Aerodynamic Performance of EMU Train under Crosswind

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ABSTRACT

EMU train and simply supported bridge of 32 m high-speed railway were chosen to study the effect of wind-break wall on aerodynamic characteristics of vehicle-bridge system under cross-wind. The numerical simulation was carried out based on three-dimensional steady N-S equation and $k - \omega$ SST turbulent model. The analysis of aerodynamic characteristics of vehicle-bridge system was taken under equivalent ventilation ratio of wind-break wall, ventilation ratio, eight of wind-break wall and wind deflection angle. The results show that: The increase of wind-break wall’s height will raise side force coefficient and moment coefficient, and show less obvious effect on lift coefficient. Wind-break wall with more railings has better windproof effect than those with less ones which share equivalent ventilation ratio. Higher wind-break wall is not always better and it means that there is a reasonable height range. Increasing ventilation ratio will raise aerodynamic coefficients of vehicle with the same wind-break wall’s height.

According to the "long-term railway network planning", by 2020, the construction of passenger line more than 12,000 km, passenger speed target value of 200 km and above. With the continuous improvement of train speed, under the action of strong crosswind, the train aerodynamic performance deteriorated, the safe operation of the train have a very negative impact. In the crosswind effect, the train in the large bridge is likely to occur overturned accident. In the Japanese Yamanote line on the step bridge, more than the train overturned wind speed of the strong wind will train to the bridge, resulting in train vehicles, rails, bridge structure damage and casualties of catastrophic traffic accidents. Since the opening of the
Lan-Xin railway in China (statistics to 2002), due to strong winds caused by the train derailment, overturning accidents up to 30, blowing trucks 110, and due to wind caused by late, outage caused by the loss is impossible Calculation\[^8\]. The wind speed and wind force on the bridge are stronger than the ground, and the coupling effect of the vehicle-bridge also makes the wind load of the train more unfavorable.

1 NUMERICAL COMPUTATION THEORY AND MODEL

The flow field around the axle is simulated by three-dimensional viscous incompressible turbulent flow. The governing equations describing the air flow around the axle include the mass conservation equation, the momentum equation and the turbulence model equation. Here, the turbulence simulation uses $k-\omega SST$ model. The concrete form is shown in the literature\[^{14}\].

Train model to select a high-speed train, its complex shape and slenderness is relatively large, by the computer processing capacity constraints, the train model to simplify the necessary. The shape of the cross section of the middle part of the high-speed train remains the same, and the aerodynamic change tends to be stable in the middle of the train\[^{15}\]. When the train is still on the bridge, the simplified model of the three carriages of the first car + the middle car + the tail car is adopted. The geometric shape of the head car and the tail car is exactly the same, and the external projection of the train is neglected. The concrete calculation model is shown in Fig. 1. The bridge with 32m simply supported beam as the research object, beam width 12.24m, beam height 3.628m, pier height of 10m, the bridge selection of three-span simple beam model.

![High-speed EMU calculation model](image)

Figure 1. High-speed EMU calculation model.

The windshield is simulated using the following assumptions: The windshield is replaced by a series of evenly distributed transverse railings, which are defined as the distance between the top and the deck of the windshield. Due to the study of the height of the wind wall and ventilation changes more, here only give part of the height of 3m different ventilation wind wall diagram, as shown in Figure 2. The surface of the windshield is expressed as $AmB-C$, where $A$ represents the height (m), $B$ is the air permeability (%), $C$ is the height $A$ and the wind barrier $B$.

The quality of the grid directly affects the accuracy and speed of the solution. In this paper, a hybrid grid scheme is adopted, using tetrahedral and hexahedral elements. In order to capture the flow of the wall surface of the vehicle body, the outer grid of the EMU is refined and the wake region grid is encrypted. As the front shape is complex, the surface is more difficult, it is difficult to take a better quality of the structured grid, so the front surface and the surrounding space using unstructured
grid. In order to capture the subtle changes in the nose air flow, the surface of the grid encryption. The results of the meshing are shown in Fig 3.

![Schematic diagram of the windscreen.](image1)

**Figure 2. Schematic diagram of the windscreen.**

![Train nose mesh.](image2)

![Train body outer surface mesh.](image3)

**Figure 3. Train nose mesh.**

**Figure 4. Train body outer surface mesh.**

The middle part of the train is simplified and its surface is relatively smooth. Therefore, the meshing is carried out in the middle of the train, and it is encrypted near the vehicle body to capture the airflow condition near the wall. The results of the meshing are shown in Fig 4.

The outer area is far away from the vehicle body, and because the train has little effect on the flow of airflow in the long distance space, the external grid can be relatively enlarged and can be structured in a structured grid. The farther away from the train, the smaller the effect, so the grid can also draw the greater, which not only reduces the total number of grids, thus reducing the calculation time, while not reducing the accuracy of the calculation. The whole grid and grid surface meshing are shown in Fig. 5 and Fig 6. The total number of computing domains is about 3 million.
2 ANALYSIS OF THE RESULTS

2.1 Bridge aerodynamic performance

In the study of the influence of the train on the aerodynamic performance of the bridge with the windshield, the aerodynamic performance of the bridge with no winds on the windward side of the bridge under the action of 10m / s cross wind is installed. Figure 7 shows the bridge section of the aerodynamic coefficient with the wind wall height of the curve.

It can be seen from Figure 7: With the height of the wind wall increases, the aerodynamic coefficient of the car bridge began to increase, and gradually more than no car bridge, but the difference is not that the wind wall more than a certain height after the car bridge Safety is lower than the car-free bridge, therefore, for the safety of the bridge itself to join the train. At the same time, the torque coefficient of the car bridge in the wind wall height of more than 3.5m after the basic no longer changes.
The windshield is consolidated with the bridge, increasing the area of the wind. On the side of the force, the higher the wind wall, the greater the pressure on the wind side, the leeward side of the negative pressure area also increased, so the bridge side force increases; on the lift, the bridge on the surface without wind wall, the wind from the wind The wind is shunted and a large negative pressure is formed near the windward surface, and then slowly decreases. When there is a windshield, the wind is divided at the top of the wind wall, and the upper surface of the bridge forms a large whirlpool that covers the transverse direction. The formation of a larger and the value of the corresponding negative pressure, close to the wind side of the negative pressure is less than no wind wall, near the leeward side of the negative pressure is greater than no wind wall. The lower surface is close to the wind side of the negative pressure, close to the leeward side of the negative pressure is small, the overall wall when the wind wall than the wind when the negative pressure; no wind wall, the upper surface near the wind surface part of the negative pressure It is very obvious, so the overall lack of wind when the wind lift, and different height of the wind wall on the bridge from the surface of the impact of no difference, lift change is not obvious; on the torque, no wind Small force, but the role of lifting point from the moment, and is positive, the torque is greater; when the height of the wind wall is greater than 1.5m, the side force has increased, and the role of point up, making the torque increases, But the lift is reduced, and the point of action is less close to the center when there is no windscreen, and the torque is reduced. With the increase in the height of the windshield, the lateral force increases, the side force action point continues to move up, the lift change is small. The lateral force is the main factor that restricts the change of the torque, so the torque increases with the increase of the lateral force.

2.2 Equivalent ventilation rate

Equivalent ventilation rate that is the height of the wind wall, ventilation rate of the same, only the number of different railing situation. Table 1 shows the wind turbine wind speed 10m/s under the action, the height of the windshield were 3.5m and 4.0m, ventilation rate of 40%, the number of railing were 5, 6 and 7 when the aerodynamic coefficient of the train.

It can be seen from Table 1 that the side force coefficient of the first car and the middle wheel decreases with the increase of the number of railing, but the descending coefficient of the head car and the middle wheel increases with the increase of the number of railing of the trend, but the increase is not large. With the increase in the number of railing, the first car and the car side force and lift the trend is the opposite. Under their mutual action, the overturning moment coefficient becomes smaller and the amount of change is relatively weak, within 3%. Overall, in the equivalent ventilation rate of the number of railings over the wind wall wind effect than the number of railings less wind wall wind effect is excellent.
TABLE 1. CROSS WIND UNDER DIFFERENT RAILINGS ON THE AERODYNAMIC PERFORMANCE OF THE TRAIN.

| Windshield type | Lateral force coefficient | Lift coefficient | Moment coefficient |
|-----------------|---------------------------|------------------|-------------------|
|                 | Head train | Central train | Head train | Central train | Head train | Central train |
| 3.5m40-5        | 0.2763 | 0.3783 | 0.4186 | 0.5004 | 0.1855 | 0.2503 |
| 3.5m40-6        | 0.2533 | 0.3648 | 0.4638 | 0.5019 | 0.1841 | 0.2461 |
| 3.5m40-7        | 0.2488 | 0.3262 | 0.4501 | 0.6734 | 0.1795 | 0.2417 |
| 4.0m40-5        | 0.2934 | 0.3693 | 0.3934 | 0.5165 | 0.1840 | 0.2454 |
| 4.0m40-6        | 0.2742 | 0.3603 | 0.4172 | 0.4860 | 0.1816 | 0.2381 |
| 4.0m40-7        | 0.2588 | 0.3458 | 0.4186 | 0.5262 | 0.1755 | 0.2387 |

2.3 Height and ventilation rate

Crosswind mainly affects the safety of the first car in the train group, or the impact of the crosswind on the train running safety is mainly reflected by the head car[3]. Under the action of wind speed of 10m / s wind speed, the variation law of aerodynamic performance of the lower head under different height and ventilation wind wall is studied. The results are shown in Fig. Each curve in Figure 8 represents the trend of the aerodynamic force of the train with the height of the windshield at the same ventilation rate. Overall, the trend of change in aerodynamic performance of the three cars is consistent. In the bridge after the installation of the wind wall, the pneumatic performance of the car has been significantly improved. At the same ventilation rate, the aerodynamic coefficient of the train decreases rapidly with the height of the windshield, but when the height of the windshield is greater than 3.5m, the degree of reduction is no longer obvious, indicating that the height of the windshield is not as high as possible. But there is a reasonable height within the range. At the same height of the windshield, the aerodynamic coefficient of the train increases with the increase of the ventilation rate.
3 CONCLUSION

(1) The increase in the height of the windshield will increase the lateral force and torque coefficient acting on the bridge, and the lift coefficient will not change obviously. Side force is the main factor that restricts the change of torque.

(2) In the equivalent ventilation rate, the number of railing windshield wall wind effect than the number of ralings less wind wall wind effect is excellent.

(3) In the bridge after the installation of the wind wall, the pneumatic performance of the car has been significantly improved. At the same ventilation rate, the aerodynamic coefficient of the train decreases rapidly with the height of the windshield, but when the height of the windshield is greater than 3.5m, the degree of reduction is no longer obvious. At the same height of the windshield, the aerodynamic coefficient of the train increases with the increase of the ventilation rate.

REFERENCES

1. Gao Guangjun, Tian Hongqi, Yao Song, et al. Effect of strong cross-wind on the stability of trains running on the Lanzhou-Xinjiang railway[J]. Journal of the China Railway Society, 2004,26(4) : 36-40.

2. Lu Guandong. Overturning moment of the train under strong cross wind[J]. Railway Car. 2008,46(9) : 9-10.
3. Ren Zunsong, Xu Yugong, Wang Lulei, et al. Study on the running safety of high-speed trains under strong cross-winds[J]. Journal of the China Railway Society, 2006, 28(6) : 46-50.

4. Xiong Xiaohui, Liang Xifeng, Gao Guangjun, et al. Train aerodynamic characteristics in strong cross-wind on Lanzhou-Xinjiang rail way line[J]. Journal of Central South University: Science and Technology, 2006, 37(6) : 1183-1188.

5. Xiong Xiaohui, Liang Xifeng, Gao Guangjun, et al. Train aerodynamic characteristics in strong cross-wind on Lanzhou-Xinjiang rail way line[J]. Journal of Central South University: Science and Technology, 2006, 37(6) : 1183-1188.

6. Suzuki M, Tanemoto K, Tatsuo M. Aerodynamics characteristics of train/vehicles under cross winds[J]. Journal of Wind Engineering and Industrial Aerodynamics, 2003, 91(1): 209-218.

7. Yang Mingzhi, Yuan Xianxu, Zhou Dan, et al. Aerodynamic forces acting on a box car running on Qinghai-Tibet railway under strong cross-wind[J]. Journal of Railway Science and Engineering, 2008, 5(2) : 75-78.

8. Ge Shengchang, Yin Yongshun. Field test research on safe operation criteria of train in wind region of Lanzhou-Xin-jiang railway line[J]. Railway Quality Control, 2006, 34(4) : 9-11.

9. Liu Fenghua. Wind-proof effect of different kinds of wind-break walls on the security of trains[J]. Journal of Central South University: Science and Technology, 2006, 37(1) : 176-182.

10. Jiang Cuixiang, Liang Xifeng. Effect of the vehicle aerodynamic performance caused by the height and position of wind-break wall[J]. China Railway Science, 2006, 27(2) : 66-70.

11. Liu Fenghua. Study on the optimization of wind-break wall of the reinforced concrete shaped type[J]. Journal of Railway Engineering Society, 2006(1) : 96-99.

12. Ge Shengchang, Jiang Fuqiang. Analyses of the causes for wind disaster in strong wind area along Lanzhou-Xinjiang railway and the effect of windbreak wall[J]. Journal of Railway Engineering Society, 2009(5) : 1-4.

13. Dong Hanxiong. Design on wind wall for hundred-mile wind field on Lanzhou-Xinjiang railway[J]. Subgrade Engineering, 2009(2) : 95-96.

14. Wang Fujun. Analysis of computational fluid dynamics[M]. Beijing: Tsinghua University Press, 2004.

15. Coleman S A, Baker C J. High sided road vehicles in crosswind[J]. Journal of Wind Engineering and Industrial Aerodynamics, 1990, 36: 1383-1392.