Research on the Operational Safety of High-Speed Train in the deep Gorge Wind Field

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Abstract. A simplified model of a high-speed train breaking into gorge wind field is constructed, and the grid-independence validation was carried out to illustrate the correction of the grid used in the simplified model. The model is used to study the flow field around the train and its aerodynamic response characteristics when the train break into the deep gorge wind field. An in-depth study was conducted to investigate the influence of the location where the train passes through the deep gorge wind field on the diffraction characteristics of the flow field around the train and the aerodynamic loads characteristics. The results show that: due to the acceleration effect of the gorge, the train's aerodynamic loads is larger when the train breaking into the deep gorge wind field at the entrance of the gorge, and the side force coefficient and overturning moment coefficient of the head car increase by 16.41% and 15.44% compared with that at the center of the gorge. The installation of windbreaks did not change the flow field characteristics when the train enters the gorge, but it can significantly reduce the aerodynamic loads. The side force coefficient and overturning moment coefficient of the head car are reduced by 80.1% and 75.7% respectively after the installation of the windbreak, which greatly ensures the safety of train operation.

Keywords: deep gorge wind; high-speed trains; wind field characteristics; aerodynamic loads

1 Introduction

Railroad transportation is an important infrastructure of a country, an important part of a country's transportation system, and an important influence on a country's political, economic, cultural and national defense construction and development. By the

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end of 2020, the mileage of China's railroads in operation had reached 146,000 kilometres, the annual passenger traffic had reached 2.203 billion people, and the annual freight traffic had reached 4.552 billion tons [1].

As an important part of China's high-speed railroad network of the Sichuan-Tibet Railway, has a special geomorphological environment, the entire line altitude difference of more than 3,000 meters, steep slopes, deep ravines and valleys, the terrain undulation. In order to eliminate the significant altitude difference, the construction of the Sichuan-Tibet Railway have to build the bridges and tunnels, so that the length of tunnels and bridges accounted for more than 80% of the total length of the line, the Sichuan-Tibet Railway line layout diagram is shown in Figure 1. And the Sichuan-Tibet area is very prone to windy weather, and the wind speed is further strengthened under the acceleration effect of the gorge. If the powerful wind is directly impacted on the train, it will lead to a large aerodynamic lateral force and overturning moment, resulting in the deterioration of the lateral aerodynamic performance of the train, which is bound to seriously affect the comfort of the train and the safety of the train operation [2]. Due to the absence of crosswinds in the tunnel, and the larger wind stays in the deep gorge wind field, there will be a large mutation load in the transition area of the tunnel and the gorge wind field, which greatly threatens the safety of train operation [3]. Under the influence of these factors, the problem of train traveling safety under the high wind environment is formed, which is exclusive to the Sichuan-Tibet region.

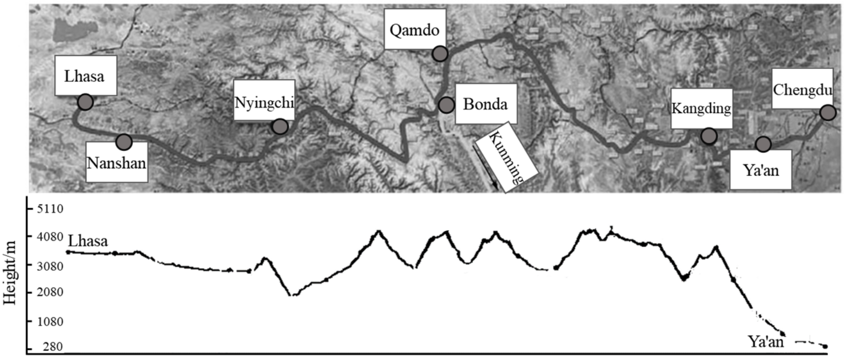

Fig. 1. The Sichuan-Tibet Railway line layout diagram.

In order to study the interactive aerodynamic effect between trains and bridges, Wang et al. [4] investigated the aerodynamic changes of a high-speed train crossing a truss bridge, analysed the effects of the incoming wind speed, wind angle and the velocity of vehicle on the aerodynamic force of the train, and described in detail the protection effect of the truss bridge on the train through numerical simulation. Deng et al. [3] used numerical simulation to study the flow field, aerodynamic performance and response of the train in the whole process of tunnel-bridge-tunnel under the crosswind condition, but they did not consider the effect of the gorge on the flow field. Wang et al. [5] used the URANS model to study the change of the flow field around the train crossing the tunnel in the crosswind. Current research on the aerodynamic performance of high-speed trains coupled with crosswind and tunnel fields on bridges focuses on the influence of the sudden change of wind speed at the transition. However, the environment of the Sichuan-Tibet line is complex, and the crosswind conditions are varied. Under the coupling effect of these parameters, there is still a research gap in the dynamic evolution of flow field structure around the train from the symmetric distribution in the tunnel to the asymmetric distribution on the bridge.

In order to enhance the safety and comfort of train operation on railroad bridges in high wind areas, a large number of scholars have comparatively analyzed the aerodynamic performance of trains under different bridge windbreaks. For example, Zhang et al. [6] investigated the effects of different windbreak heights on the aerodynamic performance of trains and bridges, and found that the transverse forces and moments of the trains decrease with the increase of the height of the windbreaks. However, it remains to be verified whether the design of bridge windbreaks for the Gobi and hilly terrain is suitable for the sudden change of loads characteristic of bridge/tunnel transitions in the windy areas of deep gorges.

To summarize, this paper takes the construction of the Sichuan-Tibet Railway as the background, and constructs a model of a train crossing a bridge-tunnel transition under a typical deep gorge wind field. This model is used to carry out aerodynamic studies when the train crosses the deep gorge wind field, and analyze the dynamic evolution of the flow field around the train and the transient aerodynamic response characteristics of the train in this process. On this basis, it analyzes the aerodynamic load optimization ability of the current protective facilities for trains when they cross the transition section of bridges and tunnels in the gorge wind area, and provides a theoretical basis for the setting of wind protection facilities in the actual gorge wind area.

2 Numerical Simulation Methods

2.1 Gorge/Train Coupling Model

Ideally, a train crossing a deep gorge wind field includes a series of processes such as the train entering a tunnel from a bright-line environment (no crosswinds), exiting the tunnel and entering a gorge wind field (with crosswinds), then passing through the tunnel again, and finally running in a no crosswinds environment. However, due to the large scale of the deep gorge terrain, the computational resources required to simulate the complete process of a train completely traversing a deep gorge wind field are immeasurable. At the same time, considering that under the combined effect of the acceleration effect of the gorge and the sudden change of wind speed (at the bridge-tunnel transition section), the lateral stability of the train will be seriously damaged, and the safety of the train will be seriously threatened. Therefore, in this paper, the numerical simulation is only carried out for the process of the train crossing the tunnel into the deep gorge wind field (inside of the gorge). Without affecting the flow field around the train, the size of the computational domain can be reduced as much as possible, in order to reduce the resources required for computation.

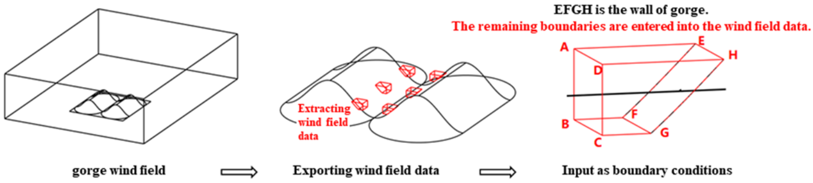

Fig. 2. Data processing flow for the gorge wind field.

In order to keep the wind field in the gorge acting on the train as constant as possible, the whole wind field calculation data were exported and then inputted into the model of the train traversing the deep gorge wind field as the boundary condition, and the whole process is shown in Figure 2.

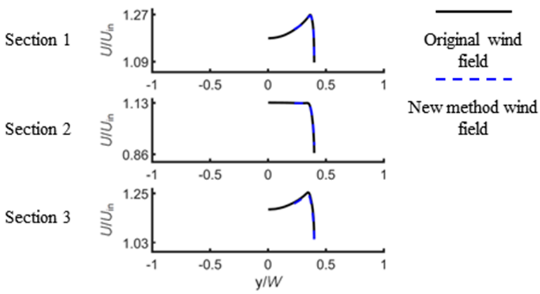

Fig. 3. Wind speed comparison.

The comparison of dimensionless wind speed U/U_{in} the entrance, the center and the exit of the gorge are shown in Figure 3, respectively. It is found that the wind speeds of the original wind field and the input wind field are basically the same, indicating that the wind field data calculated by the numerical simulation method used in this paper are basically consistent with the original gorge wind field.

2.2 Grid-Independent Validation

In order to illustrate the accuracy of the grid calculation used in this paper, three sets of grids with different sparsity were used for the grid-independent validation. As shown in Figure 4, the time course curves of the side force of each car are presented when the train passes through the tunnel and enters the deep gorge wind field. The results with mesh 1 (35.4 million grid) differ greatly from those with mesh 2 (49.7 million grid) and mesh 3 (64.9 million grid), while the side force of each car under mesh 2 are basically the same as that of mesh 3. Therefore, it can be considered that mesh 2 can satisfy the accuracy of the existing calculation, and mesh 2 is used for the subsequent numerical simulation study. Furthermore, the hear car's side force is greatest when the train is running in the deep gorge wind field, which is consistent with the study of He and Zou [7]. Therefore, the head car aerodynamic loads are compared when considering the safety of train operation in the following section.

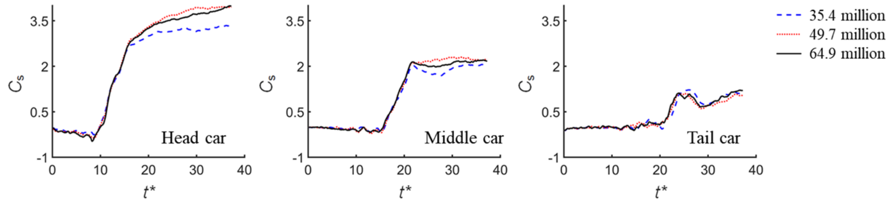

Fig. 4. The side force of each car under different mesh.

3 Aerodynamic Response of Trains Crossing Deep Gorge Wind Fields.

In this section, the transient aerodynamic response of a train operating in a deep gorge wind field is investigated in detail, the aerodynamic response characteristics of the train at different locations in the gorge wind field are compared, and the applicability of the existing wind protection facilities is investigated, so as to provide theoretical support for the subsequent research on the safety of train operation in deep gorge wind fields.

3.1 Location of the Area through the Gorge Wind Field

Due to the acceleration effect in the deep gorge, the wind speed distribution at the entrance and exit of the gorge is quite different from that at the center of the gorge. This subsection compares the diffraction characteristics of the flow field and the aerodynamic loads on the train when it enters the deep gorge wind field from different locations.

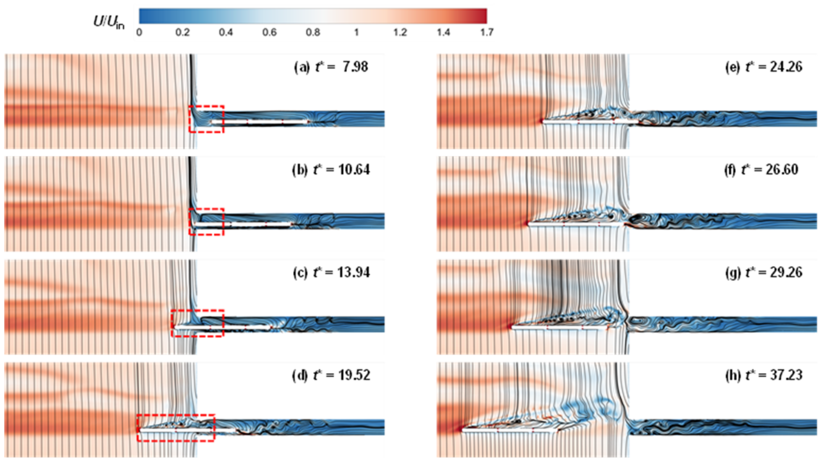

Fig. 5. Evolution of the flow field as the train breaks into the gorge wind field at the gorge center.

The diffraction process of the flow field around the train when the train breaks into the gorge wind field at the center of the gorge is shown in Figure 5, the dimensionless time is defined as t* = tvt/h. In Figure 5(a), it can be seen that when the train is running in the tunnel (t* = 7.98), the gorge forms a suction effect on the air in the tunnel, and a larger vortex is formed at the exit of the tunnel because of the large wind speed in the gorge and the small wind speed in the tunnel. When the head car completely exits the tunnel (t* = 19.52), shown in Figure 5(d), the vortices falling off can be observed on the leeward side of the head car, and these vortices and the train form a triangular region that dominates the flow field structure around the train. When the tail car completely leaves the tunnel (t* = 26.20), the flow field around the train becomes gradually free from the influence of the tunnel, but the air driven by the train leaving the tunnel forms a large vortex structure at the tunnel entrance.

Figure 6 gives a comparison of the time course curves of the aerodynamic coefficient of the head car when the train crosses the tunnel at the entrance of the gorge and the center of the gorge. During the process of the train crossing the tunnel from the entrance of the gorge into the windy area of the gorge, the aerodynamic change rule of the head car is basically consistent with that of the train crossing from the center of the gorge. However, the aerodynamic loads on the head car when the train crosses the gorge at the entrance of the gorge are obviously larger than those at the center of the gorge. The coefficient of aerodynamic force Cs and the coefficient of overturning moment Cmx both increased, by 16.41% and 15.44%, respectively. Train aerodynamic safety is worse when the train breaks into the deep gorge wind field at the gorge entrance.

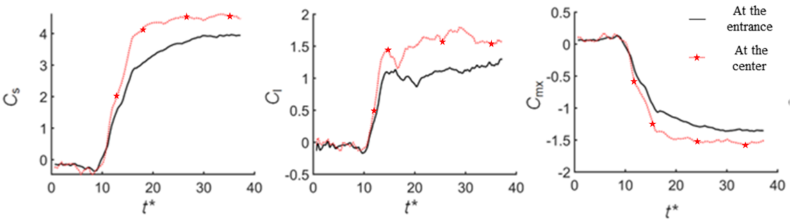

Fig. 6. Comparison of the time course curves at the entrance and the center of the gorge.

3.2 Applicability of Windbreak

This subsection focuses on evaluating the ability of the existing windbreak to optimize the safety of train operation when the train operates in a deep gorge wind field. Figure 7 shows the evolution of the flow field (at the height of half car) when the train breaks into the deep gorge wind field with wind break. It can be seen that, due to the protection of the windbreak, the speed of the air flow to the windward side of the windbreak has been greatly reduced, and many separated vortex structures have been formed on the line. However, the wind speed at the bridge-tunnel transition is still greater than that at other locations on the line, and when the train runs through the bridge-tunnel transition, it will inevitably produce sudden changes in aerodynamic loads due to the impact of the airflow. For the flow field in the tunnel, due to the shielding of the windbreak, the air is difficult to flow in the tunnel from its entrance, and the development of the flow field at the rear of the train is also relatively slow.

Figure 8 shows the comparison of the time course curves of the aerodynamic coefficient with windbreak and without windbreak. After installing the windbreak, the change trend of each aerodynamic load coefficient is basically the same as that before installing the windbreak, but the magnitude of the aerodynamic loads decreases significantly. The side force coefficient C_s decreased by 80.1%, the lift coefficient C_l decreased by 85.4%, and the overturning moment coefficient C_{mx} decreased by 75.7%. In summary, the addition of the windbreaks can greatly reduce the aerodynamic safety problems when the high-speed train break into the deep gorge wind fields.

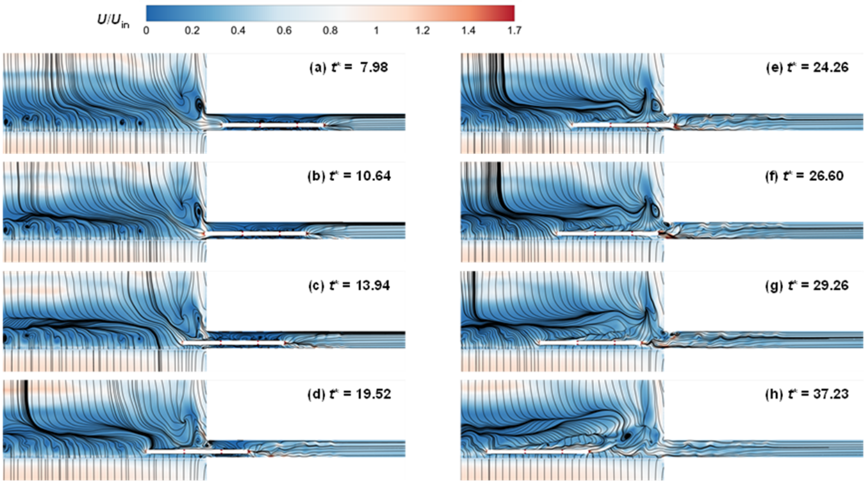

Fig. 7. Evolution of the flow field as the train breaks into the gorge wind field with windbreak.

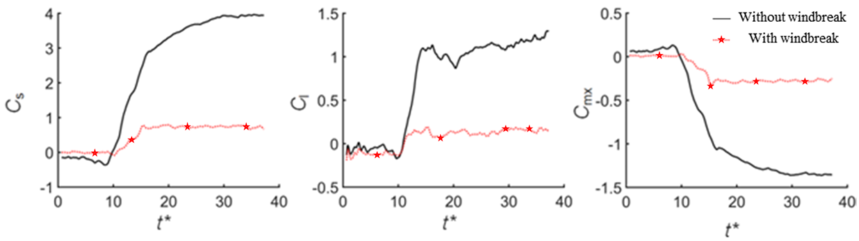

Fig. 8. Comparison of the time course curves of the aerodynamic coefficient with windbreak and without windbreak.

4 Conclusion

In this paper, the model of train crossing deep gorge wind field is simplified by exporting the simulated ideal gorge wind field data and inputting them into the truncated ideal gorge model as boundary conditions. The model is used to characterize the flow field around the train and its aerodynamic response when the train crosses the bridge-tunnel transition in the deep gorge wind field, and the conclusions are as follows:

(1) Due to the acceleration effect in the gorge, the coefficient of side force and the coefficient of overturning moment on the head car when the train breaks into the deep gorge wind field at the entrance of the gorge are larger than the aerodynamic loads at the center of the gorge, which are increased by 16.41% and 15.44% respectively. The safety of high-speed train operation is poorer when it passes through the gorge wind field from the entrance of the gorge, and the site selection of high-speed railroad line should try to choose the location at the center of the gorge to pass through the deep gorge wind field.

(2) After installing the windbreak, the trend of aerodynamic loads change are basically the same when the train is running in the gorge wind field, but the magnitude of the aerodynamic loads of the train is significantly reduced: the coefficients of the side force and the overturning moment are reduced by 80.1% and 75.7%, respectively. The windbreak can greatly reduce the aerodynamic load when the train running in the deep gorge wind field, which greatly improves the safety of high-speed train operation.

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