Wind tunnel test on aerodynamic load of express freight train on bridge under crosswind

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Abstract. With the increase of the speed of express freight train, the risk of derailment and overturning under crosswind increases. In this paper, the aerodynamic loads of express freight train on simply supported girder bridge and steel truss bridge are studied through wind tunnel test. The results show that the absolute values of transverse force coefficients and overturning moment coefficients of train increase with the increase of sideslip angle, while the lift coefficients increase first and then decrease with the increase of sideslip angle; on simply supported girder bridges, the aerodynamic load coefficients of the middle car are larger than those of the tail car, while on steel truss bridge, the aerodynamic load coefficients of the tail car are larger than those of the middle car.; the transverse force coefficients and overturning moment coefficients of the train on simply supported girder bridge are larger than those of the train on steel truss bridge, so the risk of overturning of the train on simply supported girder bridge is greater.

1. Introduction
In recent years, with the rapid development of China's high-speed railway, the capacity of existing lines has been released, and China's railway has the conditions and ability to operate express freight trains. Express freight transportation is the focus of the development of China Railway during the 13th Five-Year Plan. At present, CRRC Qiqihar Co., Ltd has completed the trial production of 160Km/h express box car[1].

With the increase of train speed, the interaction between train and air is intensified. Under the action of strong crosswind, the aerodynamic loads of train will greatly increase, which will seriously affect the lateral stability of train, and may even lead to derailment and overturning [2,3]. When train runs on bridge, the flow field around the train changes and the aerodynamic loads increases significantly[4,5]. In addition, the superposition of aerodynamic loads and vehicle-bridge coupling vibration will greatly increase the possibility of derailment and overturning of the train on bridge.

In this paper, the transverse force, lift and overturning moment of express freight train on simply supported girder bridge and steel truss bridge under crosswind are studied through wind tunnel test, which lays a foundation for the research of wind-vehicle-bridge coupling vibration.

2. Wind tunnel test
2.1. Test equipment
The test was carried out in TJ-2 wind tunnel of National Key Laboratory of Civil Engineering and Disaster Prevention in Tongji University. The wind tunnel is a horizontal closed recirculating rectangular cross-section wind tunnel with a width of 3 m, a height of 2.5 m and a length of 15 m, as
shown in figure 1. The test section is equipped with a turntable with a diameter of 2.8m which can rotate by 360°.

In wind tunnel test, the model is static, but the actual train is moving, so it is necessary to synthesize the train speed and the crosswind speed. As shown in figure 2, \( v \) is the train speed; \( w \) is the crosswind speed; \( u \) is the synthetic speed; the sideslip angle \( \beta \) is the angle between the synthetic wind speed and the reverse direction of the train speed. Obviously, the variation range of the sideslip angle is \( 0^\circ \text{ to } 90^\circ \). When the cross wind speed is 0, the sideslip angle is \( 0^\circ \). When the train speed is 0, the sideslip angle is \( 90^\circ \). The test model is installed on the turntable of wind tunnel, and the sideslip angle is changed by rotating the turntable.

The aerodynamic loads on each car are measured by a six-component force balance. The force balance is installed under the car body, as shown in figure 3.
2.2. Test model
There are two kinds of vehicle-bridge combination models in the test, train-simply supported girder bridge model and train-steel truss bridge model, as shown in figure 4 and figure 5. The model scale factor is 1:40. The train model is composed of three cars, the head car is a simulation car, whose test data does not need to be collected, set to 0.6 car. The middle car and the tail car are the test cars, whose aerodynamic loads need to be measured. The total length of the train model is 1.58m. The length of simply supported girder bridge model and steel truss bridge model are 1.80m and 1.77m.

![Figure 4. Express freight train-simply supported girder bridge model](image)

![Figure 5. Express freight train-steel truss bridge model](image)

2.3. Test content
The test content is measuring the aerodynamic loads of the middle car and tail car of express freight trains on two kinds of bridge at different sideslip angle. The train is located on the windward side of two bridges. The variation range of sideslip angle is 0°–90°. After the aerodynamic loads are measured, they are converted into dimensionless aerodynamic load coefficients, and the conversion formula is as follows:

Transverse force coefficient:

\[
C_y = \frac{F_y}{0.5\rho U^2 HL}
\]  

(1)

Lift coefficient:

\[
C_z = \frac{F_z}{0.5\rho U^2 BL}
\]  

(2)

Overturning moment coefficient:

\[
C_{ms} = \frac{M_s}{0.5\rho U^2 H^2 L}
\]  

(3)

In the formula, \(F_y\), \(F_z\) and \(M_s\) are the transverse force, the lift and the overturning moment; \(\rho\) is the air density; \(U\) is the wind tunnel blowing speed; \(H\), \(B\) and \(L\) are the reference height, the reference width and the reference length of the car model.
3. Result and discussion

The curves of the transverse force coefficients, the lift coefficients and the overturning moment coefficients of express freight train on simply supported girder bridge and steel truss bridge varying with the sideslip angle are shown in figure 6-8.

Figure 6. Curves of transverse force coefficients varying with sideslip angle

Figure 7. Curves of lift coefficients varying with sideslip angle
In both train-bridge models, the absolute values of the transverse force coefficients and the overturning moment coefficients of train increase with the increase of sideslip angle. Moreover, when $\beta < 20^\circ$ and $\beta > 70^\circ$, the increase rates are slower and the varying curves are gently, when $20^\circ < \beta < 70^\circ$, the increase rates are faster and the varying curves are steep. The lift coefficients increase with the increase of sideslip angle when $\beta < 60^\circ$, and decrease with the increase of sideslip angle when $\beta > 70^\circ$.

About the difference between the aerodynamic loads of middle car and tail car, the situations are different in two kinds of train-bridge model. In the train-simply supported girder bridge model, the aerodynamic load coefficients of the middle car are larger than those of the tail car, while in the train-steel truss bridge model, the aerodynamic load coefficients of the tail car are larger than those of the middle car.

In addition, bridge environment also affects the aerodynamic load coefficients of train. In most cases, the transverse force coefficients and overturning moment coefficients of the train on the simply supported girder bridge are larger than those of the train on steel truss bridge, so the risk of overturning of the train running on the simply supported girder bridge is greater.

4. Conclusion
The aerodynamic loads of express freight train on simply supported girder bridge and steel truss bridge under crosswind are studied through wind tunnel test. The following laws are obtained:

(1) The absolute values of the transverse force coefficients and the overturning moment coefficients of the train increase with the increase of sideslip angle, while the lift coefficients increase first and then decrease with the increase of sideslip angle.

(2) On the simply supported girder bridge, the aerodynamic load coefficients of the middle car are larger than those of the tail car, while on the steel truss bridge, the aerodynamic load coefficients of the tail car are larger than those of the middle car.

(3) The transverse force coefficients and overturning moment coefficients of the train on the simply supported girder bridge are larger than those of the train on steel truss bridge, so the risk of overturning of the train running on the simply supported girder bridge is greater.

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