9th Asia-Pacific Conference on Wind Engineering
Auckland, New Zealand
3-7 December 2017

Experimental investigation of gusty loads on trains on a truss-girder suspension bridge

Q.S. Duan[1,2,3], C.M. Ma[1,2,3]

[1]Department of Bridge Engineering, Southwest Jiaotong University, Chengdu, Sichuan 610031, China

[2]key Laboratory for Wind Engineering of Sichuan Province, Chengdu, Sichuan 610031, China

[3]Research centre for Wind Engineering, Southwest Jiaotong University, Chengdu, Sichuan 610031, China

Abstract

The flow field around railway vehicles may be greatly affected by bridge in the wind-vehicle-bridge system. Based on surface fluctuation pressure measurement, aerodynamic admittance function (AAF) and spatial correlation of gusty loads on railway vehicle, which was stationary on the truss-girder bridge, were studied. Two kinds of atmospheric turbulence fields were established in XNJD-3 wind tunnel which was 4.5m in high, 22.5m in wide and 36m in long. Meanwhile, the influence of positions of vehicles and wind attack angles on the aerodynamic characteristics of the railway vehicle were discussed.

Introduction

Trains are at risk of blowing over in high crosswind conditions. Such accidents have happened in many countries, such as China, Japan and so on [3, 4] and also have become a topic of increasing concern in recent years. One of the most critical information connected with this problem is the aerodynamic loads due to crosswind. The aerodynamic characteristics of railway vehicles under crosswinds depend not only on the shapes of the vehicles but also on those of infrastructures, e.g. bridges, embankments and flat ground [6]. In fact, trains are particularly at risk of rollover when running on exposed sites such as embankments, viaducts or long span bridges under crosswind [5] and it is of great significance to investigate the aerodynamic characteristics of trains on bridge in different turbulence fields.

Many studies have been done and mostly are on the AAF of trains which are the key non-dimensional parameters of gusty loads. Baker [1, 2] proposed an approximate form of the aerodynamic admittance which is similar to the form of frequency response function of a mass-spring-damper system. Investigations on a universal aerodynamic admittance function and a corresponding analytical weighting function for different types of trains based on a range of experimental data was made by Sterling et al. [9]. It is suggested that only two variables are required to parameterize both the admittance and weighting functions. Tomasini and Cheli et al. [10] deduced the aerodynamic admittance mathematical model of trains in crosswind and corrected it by the wind tunnel tests. At the same time, he pointed out that the lift aerodynamic admittance function doesn't match the test results very well due to the effect of vortex. Overall, study on the aerodynamic admittances of trains were mostly about the situation that the train is running on flat ground. While, when a train is travelling along a bridge in crosswind, there will be significant interaction between the wind, railway vehicle and bridge and the aerodynamic forces on trains are quite different from the ones when the train is on flat ground [7, 8].

With the development of bridge construction technology, a large number of steel truss girder bridges have been built in China, such as the Wuhan Tianxingzhou Yangtze River Bridge, Nanjing Dashengguan Yangtze River Bridge and so on. The steel truss girder section, which is sensitive to the wind action, is blunt and the aerodynamic characteristics of the train will be influenced by the truss girder. While, turbulence integral scale of the flow field in wind tunnel is smaller than sizes of the train and aerodynamic forces will also be distorted in such wind condition. The experiment was conducted in Southwest Jiaotong University XNJD-3 wind tunnel and characteristics of the flow fields simulated in wind tunnel was much closer to the wind in nature. A still wind tunnel test campaign was performed on 1:29.7 scale models. The aerodynamic admittances and spatial correlation of buffeting forces on trains on a truss-girder bridge were investigated.

Tests setup

Wind simulation

In real operation, the railway vehicle will experience different turbulent wind depending on the terrain type around railway. In order to evaluate the influence of turbulence on aerodynamic characteristics of the train, wind tunnel tests were carried out in two different atmosphere boundary layers.

Table 1 shows the values of turbulence intensity and the integral length scales of flow fields at the mid-height of the railway vehicle model, which are respectively indicated as the low and high turbulence. The low turbulence field was simulated by 13 rectangular spires whose interval space was 0.16m. The high turbulence field was simulated by roughness elements and 9 spires. The wind spectrums of the turbulence fields generated in the wind tunnel are similar to that in natural wind. And the non-dimensional power spectral density obtained experimentally under both turbulence fields is correctly interpolated by the Von Karman curve. Therefore the frequency content of the wind simulated in the wind tunnel can be assumed equivalent to the natural wind.

Types of flow	Wind speed (m/s)	Turbulence integral scale (m)			Turbulence intensity (%)		
		Lu	Lv	Lw	Iu	Iv	Iw
Low turbulence	8.81	0.65	0.29	0.22	7.95	7.28	6.03
High turbulence	9.80	0.98	0.35	0.33	11.00	9.20	8.30

Table 1 Main characteristics of the two kinds of turbulent flows.

Models

In consideration of railway vehicles currently used in China, the CRH2 passenger train was selected as the major types of railway vehicle to be investigated in this study. The external part of the vehicle was realized with a carbon fiber 2mm thick shell. The interior of the vehicle model was stiffeners to enhance the stiffness of the model. The vehicle model was instrumented with 286 pressure taps on its surface, localized on eleven transversal section (see figure 1(a) and figures 2 (a)-(b)). The other vehicle model was made of wood for the condition of intersection of two trains. The content to illustrate here was that the bottom of the vehicle was simplified as plat plane, not considering the influence of bogie, wheels, etc.

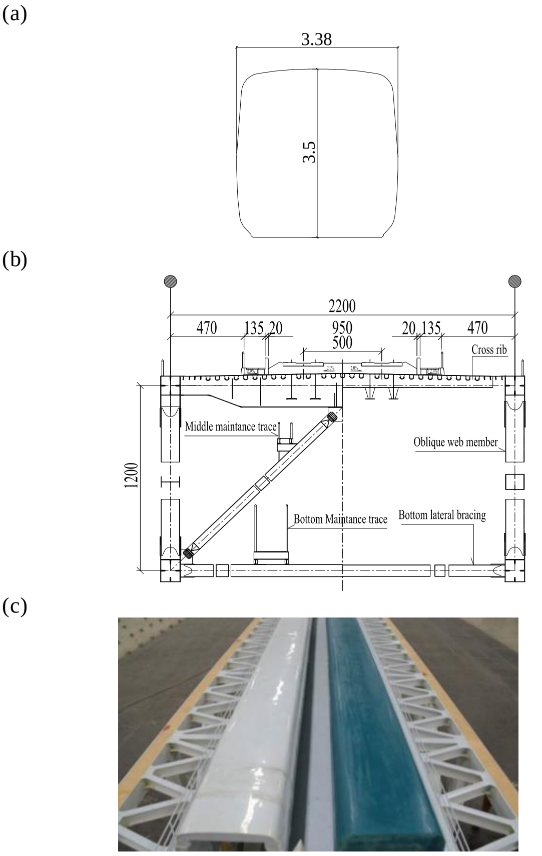

Figure 1. Cross sections of the train and bridge deck (a) Cross section of the train (unit: m); (b) Cross section of the bridge deck (unit: cm); (c) Vehicle models and bridge model

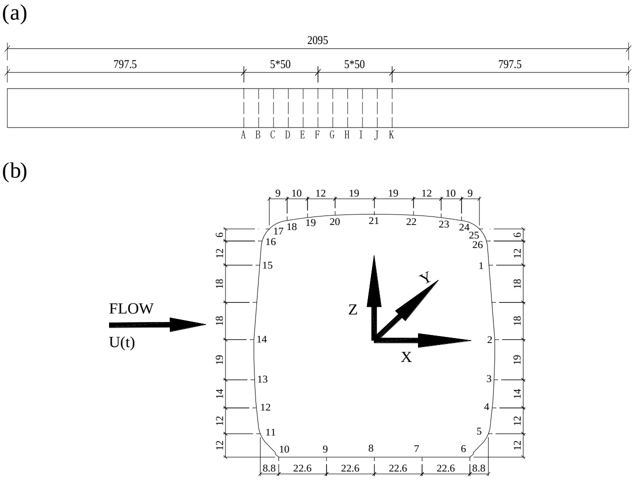

Figure 2. Positions of the pressure taps (a) Distribution of pressure measurement sections (unit: mm); (b) Distribution of taps on the pressure measurement section (unit: mm)

A steel truss girder railway suspension bridge with a main span of 660 m was taken as the example to test the influence of truss girder on aerodynamic characteristics of trains. The dimension of the girder is 22m wide and 12m high (see figure 1 (b)). The geometric scale of the deck sectional model was set as the same as the scale of railway vehicle models.

Results

Cross correlation of gusty loads

In this part, the cross correlation of buffeting forces in frequency domain is showed in figures 3-5 and different key parameters (the position of trains, wind attack angle, turbulence and span-wise distance) are considered.

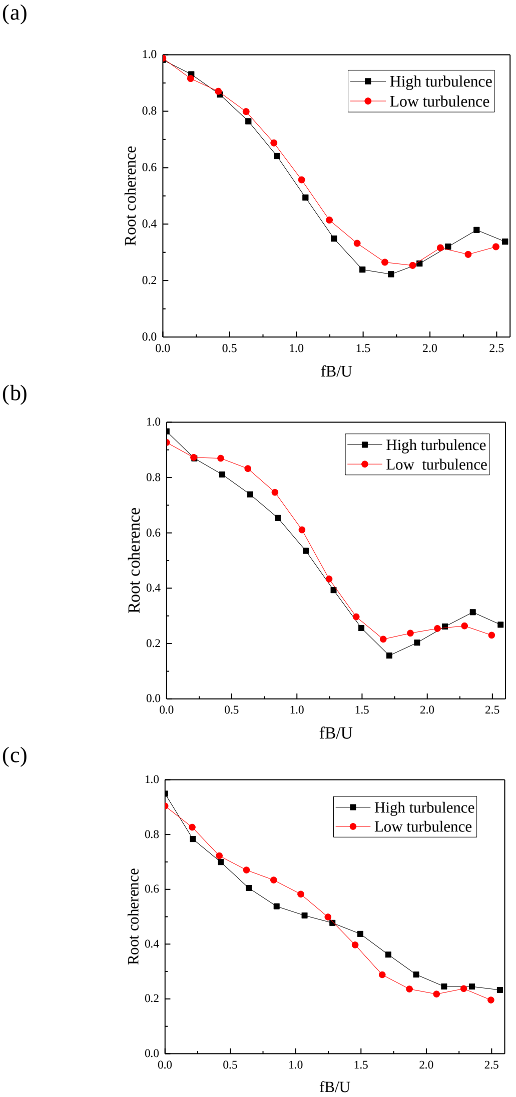

Figure 3. The cross correlation of the buffeting forces on the train in different turbulences (windward side, 0° wind attack angle, span-wise distance 0.05m) (a) Lateral force; (b) Lift force; (c) Moment

In figure 3, the cross correlation of buffeting forces is roughly the same in different turbulence flow field. While, the integral scales of the two turbulent fields are respectively about 13 times and 20 times of the span-wise space 0.05m which are both far greater than the span-wise space. In the present measurements, both the intensity and length scale were increased together and it is not possible to delineate the parameter which was responsible for the observed results. Saathoff and Melbourne [9] thinks that the ratio L_u / D is a key parameter in correlation. The values of L_u / D for two model-turbulence configurations are 2.37and 2.08 respectively and the turbulence intensity are 16% and 1.6% respectively. The agreement between the two sets of data is excellent. Maybe the influence of turbulence intensity on cross correlation could be neglected to a certain extent. So the effect of turbulence length scale on cross correlation of buffeting forces is more significant than the effect of turbulence intensity.

In figure 4, three working conditions included windward side, leeward side and intersection of two trains are considered here. It is noted that the cross correlation of buffeting forces on trains is greatly affected by the positions of trains. When the train is on the leeward side, the cross correlation of lateral forces and lift forces is relatively worse than that on the windward side. The cross correlation of the moment is better when the train is on the leeward side for the non-dimensional frequency less than 1.2. At the same time, the cross correlation of the buffeting forces decreases with the reduced frequency increases.

From figure 5, it is noted that, as the span-wise distance increases, the cross correlation of the buffeting forces becomes worse. In the low frequency region (the non-dimensional frequency less than 1.5), the correlation of the aerodynamic forces is greatly related to the ratio between the turbulence integral scale and span-wise distance. The smaller the span-wise distance is, the better the cross correlation will be.

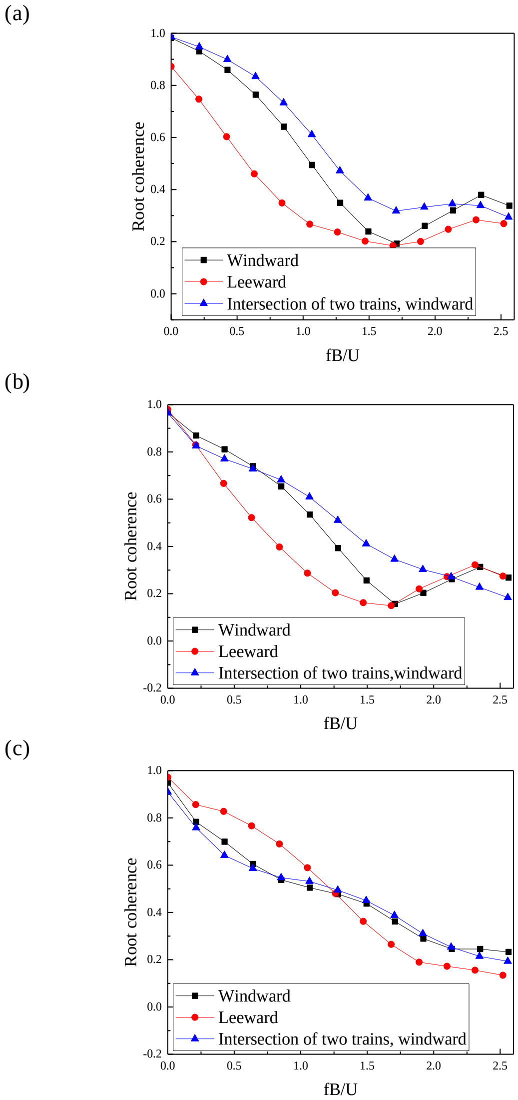

Figure 4. The cross correlation of the buffeting forces on the train at different positions (0° wind attack angle, high turbulence, span-wise distance -0.05m) (a) Lateral force ;(b) Lift force; (c) Moment

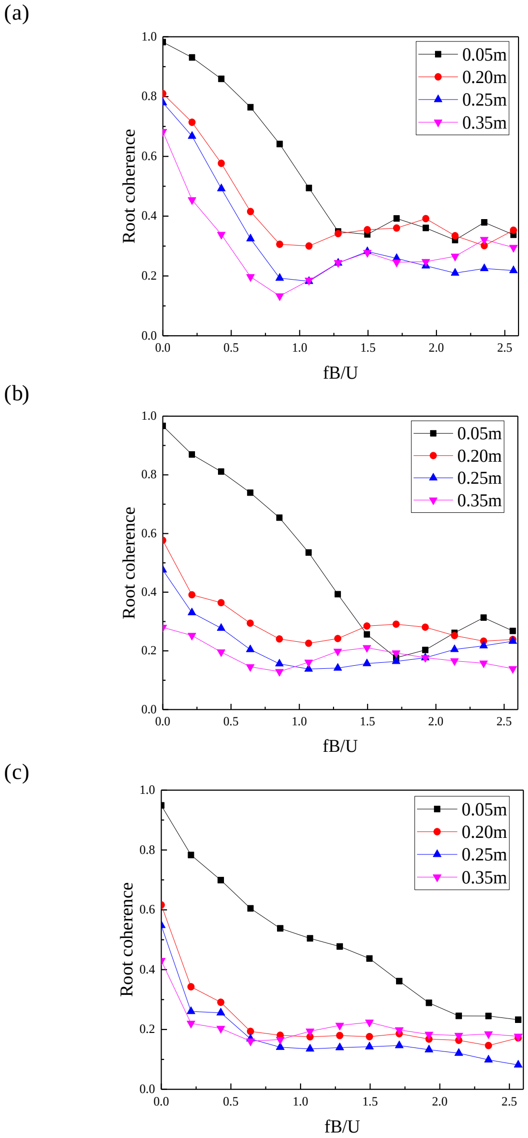

Figure 5. The cross correlation of the buffeting forces on the train at different span-wise distance (0° wind attack angle, high turbulence, windward) (a) Lateral force; (b) Lift force; (c) Moment

Aerodynamic admittances

In this part, the AAF of railway vehicles on steel truss girder suspension bridge are shown as follows. And, some key parameters (the position of trains, wind attack angle and turbulence) are considered. The results of the influence of wind attack angle and position of the train are showed in figures 6-7.

Form figure 6, it is known that wind attack angle has a great effect on the aerodynamic admittances of trains in the low frequency region. The aerodynamic admittance of lateral force is slightly larger at wind attack angle +3° than that at other wind attack angles. While, the aerodynamic admittance of lift force is larger at wind attack angle -3°. In the high frequency region, the aerodynamic admittances of the train are roughly the same.

From figure 7, it is known that positions (windward side, leeward side and intersection conditions) of the train have a great influence on aerodynamic admittances. When the train is on leeward side, the aerodynamic admittance of lateral force on the train is larger than that on the windward side (a single train or intersection of two trains) and its values are roughly larger than 1. When the train is on windward side, the AAF curves are relatively flatter than the ones when the train is on other positions.

And the aerodynamic admittance of lift force is the smallest when the train is on leeward side.

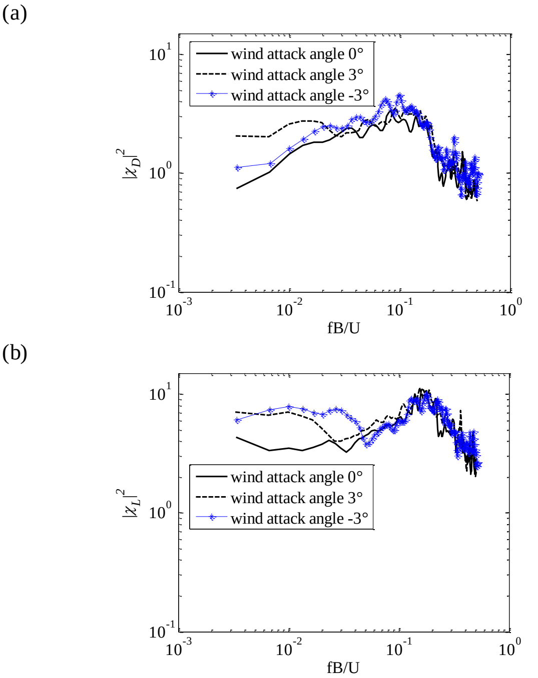

Figure 6. The aerodynamic admittances of vehicle at different wind attack angles (windward side, high turbulence) (a) Lateral force; (b) Lift force

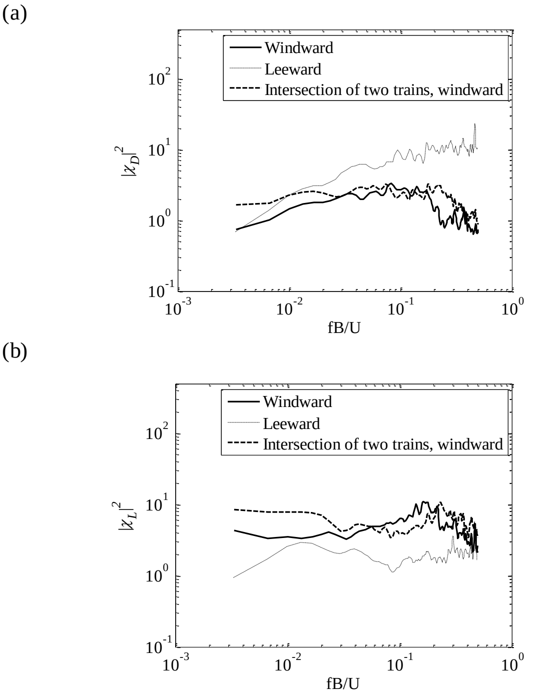

Figure 7. The aerodynamic admittances of vehicle at different positions (0°wind attack angle, high turbulence) (a) Lateral force; (b) Lift force

Conclusions

The wind tunnel experimental campaign was performed in order to investigate the aerodynamic characteristic of railway vehicles on a steel truss girder bridge in presence of two different turbulent flow fields. The cross correlation of lateral force and lift force is relatively worse when the train is on leeward side. The smaller the span-wise distance is, the better the cross correlation will be. When the train is on the windward side, leeward side, or windward side of the intersection situation, the aerodynamic admittances of the train are different. While, wind speed has little influence on the aerodynamic admittances of trains and the effect of wind attack angle on aerodynamic admittances of the lateral force and lift force is mainly located at the low frequency region.

Acknowledgments

We would like to express our gratitude for financial support from Project of Science Technology Research and Development Program of China Railway Corporation (2010G004—I)

References

[1] Baker, C.J., Ground vehicles in high cross winds part II: Unsteady aerodynamic forces, *Journal of Fluids & Structures*, **5**(1), 1991, 91–111.

[2] Baker, C.J., Ground vehicles in high cross winds part III: The interaction of aerodynamic forces and the vehicle system, *Journal of Fluids & Structures*, **5**(2), 1991, 221–241.

[3] Bocciolone, M., Cheli, F., Corradi, R., Muggiasca, S. and Tomasini, G., Crosswind action on rail vehicles: wind tunnel experimental analyses, *Journal of Wind Engineering and Industrial Aerodynamics*, **96**(5), 2008, 584-610.

[4] Cheli, F., Ripamonti, F., Rocchi, D. and Tomasini, G., Aerodynamic behavior investigation of the new EMUV250 train to cross wind, *Journal of Wind Engineering and Industrial Aerodynamics*, **98**(4-5), 2010, 189-201.

[5] Cheli, F., Corradi, R., Sabbioni, E. and Tomasini, G., Wind tunnel tests on heavy road vehicles: cross wind induced loads -Part I, *Journal of Wind Engineering and Industrial Aerodynamics*. **99**(10), 2011, 1000–1010.

[6] Dorigatti, F., Sterling, M., Rocchi, D., Belloli, M., Quinn, A.D., Baker, C.J. and Ozkan, E., Wind tunnel measurements of crosswind loads on high sided vehicles over long span bridges, *Journal of Wind Engineering and Industrial Aerodynamics*, **107-108**(8-9), 2012, 214-224.

[7] He, X.H., Zou, Y.F., Wang, H.F., Han, Y. and Shi, K., Aerodynamic characteristics of a trailing rail vehicles on viaduct based on still wind tunnel experiment, *Journal of Wind Engineering and Industrial Aerodynamics*, **135**(12), 2014, 22-33.

[8] Li, Y.L., Hu, P., Zhang, M.J. and Xu, Y.L., Aerodynamic characteristic of vehicle-bridge system under crosswind: parameters tudies based on wind tunnel test (in Cinese), *J. Southwest Jiaotong Univ*. **47**(2), 2012, 210–217.

[9] Sterling, M., Baker, C., Bouferrouk, A., Oneil, H., Wood, S. and Crosbite, E., An Investigation of the aerodynamic admittances and aerodynamic weighting functions of trains, *Journal of Wind Engineering and Industrial Aerodynamics*, **97**(11), 2009, 512–522.

[10] Tomasini, G. and Cheli, F., Admittance function to evaluate aerodynamic loads on vehicles: Experimental data and numerical model, *Journal of Wind Engineering and Industrial Aerodynamics*, **38** (2), 2013, 92-106.