Journal of Wind Engineering & Industrial Aerodynamics 175 (2018) 229–243

Contents lists available at ScienceDirect

Journal of Wind Engineering & Industrial Aerodynamics

journal homepage: www.elsevier.com/locate/jweia

Flow structure and aerodynamic behavior evolution during train entering tunnel with entrance in crosswind

Weichao Yang, E. Deng, Mingfeng Lei *, Pingping Zhang, Rongshen Yin

School of Civil Engineering, Central South University, Changsha, China

ARTICLE INFO

Keywords:
High speed train (HST)
Infrastructure scenario
Tunnel aerodynamic
Crosswind
Derailment

ABSTRACT

Transient variations in aerodynamic loads are one of the most vital causes of train overturning or derailment. Different infrastructure scenarios display the diversity of corresponding flow structures and aerodynamic load acting to vehicles. Entering a tunnel from crosswind condition is the most common aerodynamic environment of train operation. In this process, a sudden changes of the aerodynamic load on vehicle could increase the risk of derailment and overturning. Using a three-dimensional unsteady compressible flow, the transient variations of flows and pressures structure as a train enters a tunnel with the entrance in crosswind condition is studied. Furthermore, the correlations between the behavior and the temporal evolution of both the aerodynamic coefficients and their change rates have been discussed qualitatively based on lateral force, lift force, overturning moment, yawing moment, and pitching moment. Results showed that transient variations of the flows and pressure structure occurs in both horizontal and vertical direction, and their demarcation line just keeps in stationary at the tunnel entrance, as train moves into tunnel gradually. Because of crosswind located at tunnel entrance, the train's swing movement is manifested as a complex behavior including pulse oscillation, hunting movement and pitching behaviors etc. Besides the aerodynamic coefficients, the change rate of aerodynamic coefficients also seems to be a referential index of hazard assessment of running train for their synchronization. The safety factor of the leading carriage may be an important indicator of the safety assessment of the train during running from an open air in crosswind into a tunnel.

1. Introduction

Crosswinds are an important factor affecting the running safety of high-speed trains (HST). Strong crosswinds induce train derailment and overturning accidents in many countries (Baker, 1991a, 1991b; Baker et al., 2009; Li et al., 2015). The issues have caught the attention of many scholars in the last decades, and the aerodynamic characteristics in different infrastructure scenarios in crosswind conditions have been investigated in detail, e.g., flat grounds (Cheli et al., 2010; Shao et al., 2011; Cui et al., 2012), embankments (Tomasini et al., 2014; Bocciolone et al., 2008; Schober et al., 2010; Baker, 1985; 1991a, 1991b; Suzuki et al., 2003; Cheli et al., 2010; Diedrichs et al., 2007), the viaducts (Bocciolone et al., 2008; Diedrichs et al., 2007), and wind barriers (Bocciolone et al., 2008). Research shows that in crosswind conditions, different infrastructure scenarios display the diversity of corresponding flows and pressures structure (Tomasini et al., 2014).

When a train moves from one infrastructure scenario into another, the transient variations of the pressure field and the aerodynamic load rapidly switch with the change of infrastructure, which are often a vital cause of train overturning or derailment. For example, Tian, (2010) reported an overturning accident involving a train entering a wind barriers scenario in a hundred-mile wind zone in the Lan–Xin line (Lanzhou–Xinjiang Urumuqi), China (Fig. 1), in which the first five carriage overturned at the end of barrier. The analysis revealed that the overturning accident was directly caused by the complex flows structure at the end of the wind barrier and transient variations of aerodynamic coefficients on vehicle during train passing by.

When a train enters a tunnel from an open air in crosswind, the aerodynamic coefficients of the train would change more violently for the closed characteristics of tunnel is to be preferred over other infrastructure scenario. In an open air, the asymmetry of flow field on both sides of the train causes unbalance of the aerodynamic pressure. On the contrary, after the train enters a tunnel from the open air, the aerodynamic load is unloaded instantaneously, and the pressure on both sides tends to be balanced, leading to the instant horizontal swinging of the train body as it moves. The transient variation of the aerodynamic load is

* Corresponding author. School of Civil Engineering, Central South University, Shaoshan South Road NO.22, 410075 Changsha, China.
E-mail addresses: 15459220@qq.com (W. Yang), mingdfenglei@csu.edu.cn (M. Lei), 1915813198@qq.com (P. Zhang), 1725896561@qq.com (R. Yin).

https://doi.org/10.1016/j.jweia.2018.01.018
Received 4 July 2017; Received in revised form 10 January 2018; Accepted 12 January 2018

0167-6105/

Fig. 1. Train overturning induced of variations of aerodynamic loads around wind barrier.

Fig. 2. Wind barrier formed cut-and-cover tunnels.

one of the most unfavorable factors affecting the safety of running trains. Until now, a few works have been performed on the issue of sudden change of aerodynamic loads when a train moves from crosswind into tunnels. In order to simulate the actual running conditions of a rail vehicle, the moving model test, consisted of a launching ramp, running model train and a tunnel is set-up by Bocciolone et al. (2008). The train is accelerated by launching it down the ramp. At the end of the ramp, it enters a tunnel (which is long enough to completely shield one coach), and finally it is suddenly subjected to crosswind action.

In fact, the ends of a tunnel are generally connected to a canyon area generally. When airflow enters the gorge between two mountains from an open air, it flows quickly close to the rock wall, and forms a canyon wind (Ivančan Picek and Tutiš, 1996). The wind speed, the maximum of which is 69 m s^{-1}, is affected by topography and climatic conditions (Bajić and Peros, 2005). In addition, as a solution to ensure the running safety of HST, wind barriers shaped of tunnels are set in the northwest gale zone of China (Fig. 2). The most common aerodynamic environment involves a train from an open air in crosswind rapidly entering a tunnel. The impact of such an environment on the safety of train operation is evident.

For many years, with respect to the running train's safety effect induced of sudden change of the aerodynamic loads, it has been thought that aerodynamic forces evolution could be considered as quasi-static, and that it would be sufficient to measure the steady force coefficient of a static yawed model to predict vehicle behavior in crosswind, such as Beauvais (1967), Chadwick (1999) and Kobayashi and Yamada (1988), Baker and Humphreys (1996). The main goal is usually to evaluate the ratio between the unsteady efforts peaks and the corresponding values resulting from the steady state case. But, little agreement was found between the results for the data discrepancy and difference of methods (Volpe et al., 2014). Most of the authors, such as Beauvais (1967), Baker and Humphreys (1996), Chadwick (1999) agree that this ratio is 1.2–1.5, whereas and Kobayashi and Yamada (1988) measured yaw moment peaks up to more than the double of the static force. Also, Baker and Humphreys (1996) studied the influence of the yaw angle and found out that the peak overshoot tends to disappear in the range between 40° and 60°. Therefore, Cheng et al. (2012) asserted that the capturing the time-resolved aerodynamic properties is important because steady-state estimation tends to underestimate (or overestimate) the dynamic response.

Such considerations lead the authors to assert that the safety risk of running train due to the transient variation of aerodynamic loads should be based on such presuppositions: (1) the basic mechanism on the evolution of flow structure; (2) the change process of aerodynamic loads on the vehicles induced of flow structure; (3) the transparent motion behavior of running train based on the sudden change of aerodynamic loads. In which, a simple method based on very simple, easily understood mechanics principles, taking account of the train's movement characteristics, is generally to be preferred (Baker, 2013). As far as the mechanics principles are concerned, the change rate of aerodynamic loads may be an important index to assess the safety of running train, for which