J. Wind Eng. Ind. Aerodyn. 145 (2015) 351–361

Contents lists available at ScienceDirect

Journal of Wind Engineering and Industrial Aerodynamics

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

Ballast flight under high-speed trains: Wind tunnel full-scale experimental tests

A. Premoli, D. Rocchi, P. Schito, C. Somaschini*, G. Tomasini

Politecnico di Milano, Department of Mechanical Engineering Via la Masa 1, Milano, Italy

ARTICLE INFO

Keywords:
Flying ballast
Train aerodynamics
High-speed railways
Wind tunnel
Full-scale experiments

ABSTRACT

The flying ballast phenomenon has become an important problem, in the last years, because of the development of high speed trains and the consequent increase of the speed up to 350 km/h. The problem is very complex since it is related to both railway infrastructure and train characteristics and since it involves mechanical and aerodynamic effects. The results of an experimental study carried out on the Italian high-speed railway and on a 1:1 real stretch of the railways in wind tunnel are presented in the paper. The study was aimed to analyze the effects of the height of the ballast level, the stone shape in the upper layer of the ballast and the compaction of the ballast bed on the problem. To this purpose a specific wind tunnel test rig was designed to reproduce in the wind tunnel a flow with the same average characteristics of the one measured on the real line, especially in the region close to the ballast and sleepers. Finally, starting from the results of these tests, possible countermeasures to ballast lifting on-set are proposed.

1. Introduction

The phenomenon of ballast-flying is one of the major problems caused by the increase in railway speed over 300 km/h in terms of safety and early deterioration of both rolling stock and railway.

Generally, the ballast lifting phenomenon can arise also at low speed, due to external agents as ice or other materials on the line (Jing et al., 2012; Kaltenbach et al., 2008). On the other hand, the problem becomes extremely evident increasing the speed, when the ballast stones are lifted up due to the pressure and velocity field generated in the upper layer of ballast by the train. The consequences of this phenomenon are different: on the safety of the people working along railway lines, on the running safety of the trains themselves, and, finally, on the extra costs associated to both the rolling stock and the infrastructure maintenance (problem of ballast pitting, Quinn et al., 2010).

Furthermore, nowadays the issue of ballast-lifting is not regulated and limited by any international standard. For this reason, in the last years, within two European projects, Aerodynamic in Open Air (AOA within the DEUFRAKO project, 2006–2008) and Aerotrain (2008–2012), the main infrastructure managers and rolling stock constructors (SNCF, DB, RFI, Alstom, AnsaldoBreda, Bombardier, RENFE and ADIF), as well as the most important research groups on railway problems (University of Birmingham, POLIMI, University of Madrid) collaborated to analyze this specific item.

Within both these projects, different experimental campaigns were performed: in field, to characterize the air flow in the underbody zone (Kaltenbach et al., 2008; Sima et al., 2011), and in wind tunnel, trying to identify the most important parameters and the thresholds associated to the ballast lifting phenomenon.

In particular, the first experimental campaign was carried out in the SUMKA wind tunnel on 1:10 scale models of the track with the target of defining, for each of them, the mean wind speed threshold when the ballast flying comes up. The results are useful in terms of comparison between different track configurations but not in terms of absolute value due to the simplified operating and boundary conditions. A second experimental campaign was performed in the CSTB wind tunnel (Saussine and Paradot, 2011) on 1:1 scale model. In these tests, the boundary condition due to the train passing is reproduced by a model of the train underbody zone statically set over the ballast, the vibration induced by the vehicle passage is reproduced by moving a sleeper in vertical direction and a gust is reproduced by a sudden opening of a grid.

Moreover, the researchers of the Korea Rail-Road Research Institute conducted tests in wind tunnel to highlight the influence of shape and weight of the stones on the lifting phenomenon but without any modelization of the infrastructure track (Kwon and Park, 2008). Similar studies, focused on the effect of the shape of the stones and performed by numerical simulations, are described also

* Corresponding author. Tel.: +39 0223998466.
E-mail address: claudio.somaschini@polimi.it (C. Somaschini).

http://dx.doi.org/10.1016/j.jweia.2015.03.015
0167-6105/

in Sanz-Andres and Navarro-Medina (2010), and Lazaro and Gonzalez (2011).

The present paper deals with the study of the ballast lifting phenomenon using wind tunnel tests on a 1:1 track ballast section, with real sleepers, rails and stones. The aim of the research is to investigate the effects on the critical wind speed when the stones begin rolling or flying of the following parameters:

- height of the ballast level with respect to the top of sleeper;
- shape and weight of the stones in the upper layer of ballast;
- compaction of ballast.

First of all, a trackside measurements' experimental campaign was performed in order to measure the flow in the underbody region of the vehicle and the accelerations induced by the train passage on the ballast (Giappino et al., 2013). These measurements were adopted to model the experimental conditions during the wind tunnel tests. In particular, specific attention was paid to reproduce the vertical velocity profile, especially close to the ballast level. For this reason, a square cylinder was placed before the test section so that the accelerated flow obtained was comparable with the one measured in the experimental tests on the Italian high-speed line.

Moreover, the ballast was moved according to the measured vertical acceleration by means of a hydraulic actuator.

The tests were performed in the 4 m × 4 m test section of the Politecnico di Milano wind tunnel, whose maximum wind speed is 55 m/s.

Starting from the results of these tests, possible countermeasures to ballast lifting on-set are proposed in the conclusions.

2. Trackside experimental tests

In order to characterize the flow in the underbody region and the dynamics of the whole track (rail, sleepers and ballast), several experimental campaigns were carried out on the Italian high-speed network on the lines Milan–Turin (Alice, Recetto and Greggio) and Rome–Naples (Cassino). The objective was to measure both the aerodynamic variables (air pressure, velocity profile over ballast and aerodynamic loads on stones) and the mechanical vibrations of the railway infrastructure due to the train passing. In this paper only the main results, useful for the design of the wind tunnel test campaign, will be shown; the complete data analysis of these field experimental campaigns is presented in Giappino et al. (2013).

2.1. Flow velocity profile

2.1.1. Experimental setup

In order to measure the flow velocity field between the train underbody and the ballast surface, different types of transducers were used. In particular the measurement setup was composed by the following:

- a vertical array of five pitot tubes (see Fig. 1), set 20 cm apart from the middle of the rails, able to measure the vertical profile of the longitudinal component of the flow velocity;
- a single pitot tube, 20 cm apart from the center of the track and opposite to the array, to verify the symmetry of the flow;
- a multi-hole probe, in the middle of the rails, to measure the three components of the flow velocity in the central section and to describe, together with the pitot tubes, the horizontal profile of the speed;
- a cube with 32 pressure taps to evaluate the aerodynamic forces acting at the level of the ballast.

Moreover, several accelerometers were placed over rail, sleepers and ballast stones to characterize the accelerations of the whole track (Fig. 2).

During the experimental campaigns many train passages were registered with different speeds in order to enlarge the statistical basis of the analysis. Furthermore, exploiting the different speeds of the trains, it was possible to point out the independence of the profiles from the speed itself and from the Reynolds number. In this

Fig. 2. Layout of the accelerometers on sleepers and ballast.

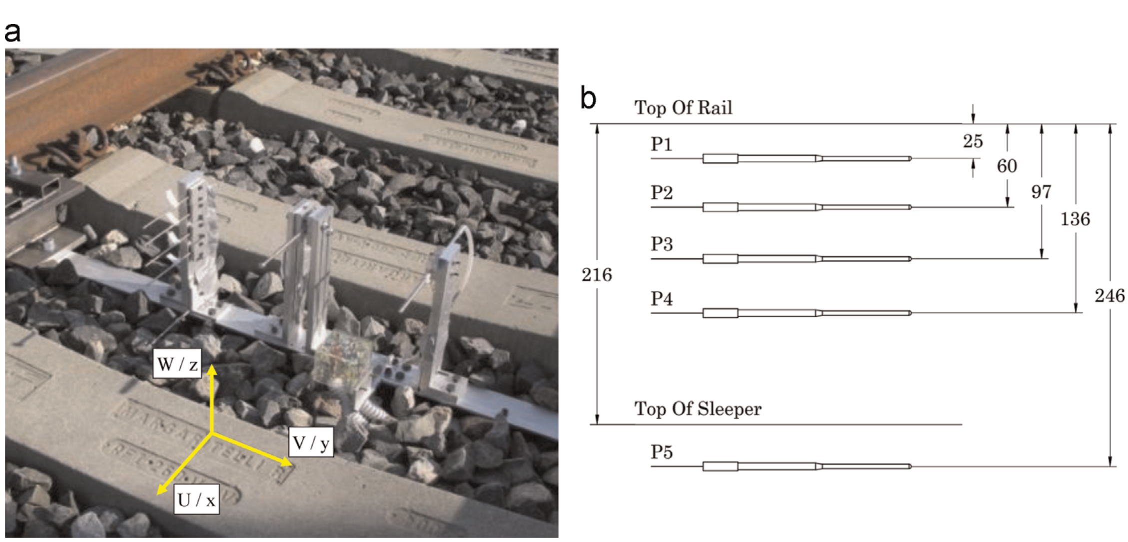

Fig. 1. Experimental setup for the flow measurements.