Engineering Structures 81 (2014) 22–34

Contents lists available at ScienceDirect

Engineering Structures

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

Effects of bird protection barriers on the aerodynamic and aeroelastic behaviour of high speed train bridges

M. Ogueta-Gutiérrez *, S. Franchini, G. Alonso

IDR/UPM, E.T.S.I. Aeronáuticos, Universidad Politécnica de Madrid, E-28040 Madrid, Spain

ARTICLE INFO

Article history:
Received 23 May 2014
Revised 18 September 2014
Accepted 19 September 2014

Keywords:
Bird protection barrier
High speed train
Bridge
Aerodynamic
Aeroelastic

ABSTRACT

Bird protection barriers on high speed train bridges may have an impact on the aerodynamic and aeroelastic behaviour of these structures. On the aerodynamic static loads on the bridge deck, the conclusion is that the most porous barriers (barriers with handrails) do not modify substantially the aerodynamic loads; however, barriers with solid screens increase the intensity of these loads, in some cases significantly. No significant difference is found between barriers with straight or curved tubes. Regarding the static load on the train, only barriers with acoustic protection screens decrease the lateral load and the turning moment significantly. Again, no significant difference is found between barriers with straight or curved tubes. Finally, concerning the effect of the barriers on the air flow on the catenaries, the conclusion is that barriers with solid screen produce a very intense perturbation in this flow, both in the windward and leeward catenaries. On the contrary, the barriers with handrails (porous) practically do not alter the flow on the catenaries.

1. Introduction

High speed train networks are expanding in different countries, improving the connectivity and reducing travel times. The environmental impact of these new infrastructures cannot be neglected. One of these environmental impacts is the effect on the avifauna. An especially critical case is that of bridges in elevated areas, because they interfere more directly the birds' flight. Collisions of big birds such as different types of eagles and vultures against the bridge deck and the catenaries are relatively frequent and a concern in protected areas [1–5]. To avoid the irruption of the birds, the usual practice is to install barriers around the railway. The presence of these barriers can greatly influence the normal operation of the railway, affecting catenaries and vehicles through the railway due to wind. Being placed in wind-sensitive bridges, they can also influence in the stability of the bridge.

Modern structures such as bridges or skyscrapers are becoming more and more slender and lighter. The consequence is that wind loads are increasingly important in the sizing of these structures. Because of this slenderness, nowadays not only static loads must be taken into account in the design of bridges, but also dynamic loads. Natural frequencies of the bridges have been significantly reduced, and this effect has put the focus on aeroelastic instabilities, such as flutter and vortex induced vibration (VIV). Flutter is an unbounded vibration known to be the cause of the Tacoma Narrows Bridge collapse [6]. VIV is, on the other hand, bounded in amplitude and in the velocity at which it occurs. The shedding of vortices alternatively form the upper and lower surfaces creates alternative loads that make the bridge vibrate when the shedding frequency matches one of the natural frequencies of the bridge [7]. The fact that it is a bounded phenomenon does not make it a second order problem. Due to VIV, the bridge may suffer fatigue loads, but it can also be closed because of the discomfort that this movement can cause in the users. As high speed trains require very controlled environment, bridge design must be optimized to eliminate this phenomenon. One of the most influential elements that can condition the behaviour of the bridge is the shape of the barriers. Solid barriers are known to destabilize the bridge, but they offer the best protection for the users of the bridge. Larsen and Wall mark New Jersey type barriers as the most likely to trigger VIV [8]. Despite the big amount of investigation performed on this issue [9–11], some newly built bridges still suffer VIV. Storebælt Bridge is one of the most remarkable examples [7,11]. Larsen and co-workers concluded that the installation of guide vanes in lower part of the deck would significantly reduce the vibration [12]. The Kessock bridge also suffered this type of oscillation in the spring of 1992 [13]. The designers had detected that the section was VIV-prone during erection and in the final stage and installed tuned mass dampers, [14], but they did not perform as expected.

* Corresponding author. Tel.: +34 913366353; fax: +34 913366363.
E-mail address: mikel.ogueta@upm.es (M. Ogueta-Gutiérrez).

http://dx.doi.org/10.1016/j.engstruct.2014.09.035
0141-0296/

Not only the deck can suffer VIV, but also other elements of the bridge. Hangers in the case of suspension bridge are typical elements prone to vibration. In the case under study, rods forming the barriers have cylindrical sections that could suffer VIV. Despite that, their rigidity is high and their natural frequencies big. By means of this, the wind velocity at which they suffer VIV is increased. Therefore, the VIV of rods has not been considered.

In order to analyse aeroelasticity behaviour of bridge it is a common practice to perform the well-known wind tunnel Ambient Vibration Test in the preliminary stages of a new project. Some examples of these tests can be seen in [15,16], where the authors say that these tests correctly match the observations in the prototype scale. More recently, these tests have been used by Ricciardelli to study the stability of the Sunshine-Skyway bridge [17], or by Matsumoto to understand the interaction between Kárman vortex street and motion induced vortices [18].

The effect of the cross wind in the stability of vehicles is known. In [19], several wind tunnel tests are performed to study the influence of the infrastructure in the lateral force on the train.

Another effect that the barriers may have is in the catenary of the railway. The shear layer generated by the detachment of the flow in the barrier can induce undesired movement in the catenary. Ávila-Sánchez et al. performed wind tunnel visualization and hotwire tests to evaluate the influence of different parapets on the position of the catenary, concluding that the turbulence generated by the barriers greatly affects the catenary [20].

The general purpose of this study is to analyse different aspects of the effects of bird protection barriers on bridge decks. For four models of barriers (plus some minor variants), the aerodynamic load over the bridge and its aeroelastic behaviour has been studied. The effects of each model of barrier on the train and the catenaries have been also investigated. Finally, the aerodynamic behaviour of the elements of the barriers has been determined. These researches have been developed by means of different wind tunnel experimental techniques. In order to achieve the objectives of the study, it has been necessary to build three different test models, adapted respectively to the corresponding tests.

The contents of this paper are organized as follows. Section 2 is devoted to explain the different experiments and set-ups used during this campaign. In Section 3, the main results of the wind tunnel tests and its analysis are presented. Finally, in Section 4, the main conclusions are extracted.

2. Experimental set-up

In order to perform the study mentioned above, a section of the bridge deck has been selected. The chosen geometry corresponds to one of the most used sections of railway bridges in the Spanish high-speed rail network, and it can be seen in Fig. 1.

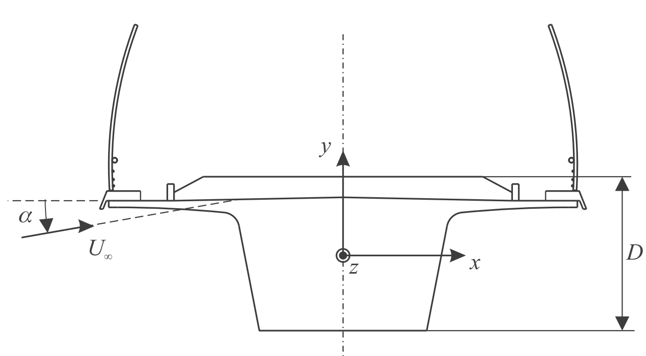

Fig. 1. Bridge deck aeroelastic test model section.

Four types of wind tunnel tests have been performed over different configurations:

- Determination of the global aerodynamic loads on the bridge section.
- Determination of the aeroelastic behaviour of the bridge.
- Study of the effects of the barriers on the aerodynamic loads on trains.
- Determination of the wind conditions (velocity, turbulence intensity) on the catenaries.

Several tests models have been built in order to accomplish these tests. Two models of the chosen section of the bridge deck at a 1:33 scale. One of the models is dedicated to the aeroelastic tests, and the other one for the aerodynamic static tests. In Table 1 the geometrical and mechanical properties of the chosen bridge deck and the corresponding aeroelastic test model are summarized. The geometrical parameters are represented in Fig. 1, together with the incident wind direction and the angle of attack.

Four different models of bird protection barriers for each bridge deck model have been constructed. They are 151 mm high, corresponding to 5 m at real scale, and they are made out of a set of vertical tubes of 3 mm diameter (100 mm at real scale), separated 30 mm (1 m at real scale). Two of the models include a handrail at the lower part, and the other two a solid acoustic barrier of 9.1 mm (3 m at real scale). In Fig. 2 an scheme of the four models are presented, together with the name given to each configuration. Finally, a sectional model of a typical high speed train has been constructed, which consists of the prism shown in Fig. 3.

2.1. Aerodynamic loads on bridge section

These tests were performed to determine the mean aerodynamic coefficients on the bridge deck test model. Fig. 4 shows a photograph of the model installed in the wind tunnel. Aerodynamic forces were measured with a six component balance Delta SI 330-30 from ATI Industrial Automation, located beneath the wind tunnel floor. The set model and balance were supported on a turning platform from NEWPORT, used to control the angle of attack. The instrumentation includes also a Pitot tube (Airflow model 3.3.311), a pressure transducer and a data acquisition system. The model was located very close to the wind tunnel floor, and a platform generating a specular surface has been placed on top of it, to get the bidimensional flow condition.

The tests consist in measure the aerodynamic forces, varying the angle of attack between −6° and 6°, each 2°. The loads have been acquired during 30 s, at a sample frequency f_s = 500 Hz. This procedure has been repeated for the fifteen configurations described in Table 2. Notice that the influence of the presence of the train was also studied.

All these tests were performed on the A9 wind tunnel of IDR/UPM. This is a low-speed closed return wind tunnel with a closed test section, which has a rectangular cross section with 1.8 m height and 1.5 m wide (Fig. 5). The wind tunnel is driven by 9 fans, 7.5 kW each one. The wind speed is controlled electronically

Table 1
Geometrical and mechanical properties of the bridge deck and the corresponding aeroelastic test model.

Property	Bridge	Model
Deck depth (m)	4.62	0.14
Mass per unit length (kg/m)	37005	33.98
Mass moment of inertia per unit length (kg·m^2/m)	4.7×10^5	3.96×10^{-1}
Bending frequency (Hz)	1.88	3.23
Torsion frequency (Hz)	11.3	–