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# Characterisation of cross-flow above a railway bridge equipped with solid windbreaks

S. Avila-Sanchez [a,*], O. Lopez-Garcia [a], A. Cuerva [a], J. Meseguer [b]

[a] Dpto de Aeronaves y Vehiculos Espaciales, ETSIAE, Universidad Politecnica de Madrid, Spain
[b] IDR/UPM, ETSIAE, Universidad Politecnica de Madrid, Spain

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## ABSTRACT

The flow field above a two dimensional model of a railway bridge equipped with solid windbreaks is analysed in a wind tunnel. Particle image velocimetry (PIV) is used to measure the flow velocity in planes perpendicular to the bridge span. The mean velocity components, the two-component turbulent kinetic energy, the turbulence intensities of the velocity fluctuation components and the Reynolds shear stress above the bridge deck are presented. The flow patterns based on the streamlines of the average flow field are analysed. The inclusion of a windbreak produces a separation bubble, that is locked to the bridge deck due to presence of the leeward fence. Special attention is paid to the analysis of the flow field characteristics along the vertical profiles above the railway tracks. The inclusion of the windbreak leads both to an increase of the mean velocity and the turbulence intensity around the catenary contact wires. On the other hand, the flow in the region close to the bridge deck is slowed-down. The effect of the size of the final interrogation window used in the PIV analysis is considered, more particularly on the determination of the mean velocity and turbulence intensity. The results show that a decrease of the final interrogation window leads to an increase of the turbulence intensity when there are no wind protection devices installed on the bridge.

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## 1. Introduction

The interaction between wind and civil engineering structures has focused the attention of several studies since the XIX century [1,2], since the safe operation of these last ones are strongly affected by wind loads. The railway transport system is an example of an infrastructure that is affected by wind actions. For instance, cross-wind can strongly compromise both the structural integrity and the safe operation of the rolling stock [3]. One of the most relevant problems is the wind-induced dynamics of the contact wires which are equipped by railway overheads. From the aerodynamic point of view such contact wires can be considered as non-circular cross-section cables [4] exposed to atmospheric turbulent flow. With regard to the characteristics of the wind-induced dynamics of contact-wires, it is known that wind actions on non-circular geometries could eventually trigger aeroelastic instabilities such as galloping phenomena [5–8]. In fact, Johnson [3] and Scanlon and Oldroyd [9] have extensively reported on the susceptibility to suffer undesirable wind-induced phenomena, of the cable system that composes the railway overhead. These phenomena have adverse effects on the operation of the system. For instance, under the effect of cross-winds, large amplitude oscillations due to cable galloping of railway overheads have lead to the delay and cancellation of train transits at several locations of Scotland [10] and the British East Coast Main Line [11].

On the other hand, cross-winds and the shape of both the vehicle and the surroundings are crucial factors on the resulting aerodynamic loads on trains [12]. These aerodynamic loads may lead to train overturning if the cross-wind speed reaches a threshold value, summarised in the Characteristic Wind Curve (CWC) [13], specially because train speeds have risen significantly over the last decades. The overturning risk increases when moving vehicles travel along exposed locations such as bridges or embankments. The wind speed in the atmospheric boundary layer normally grows as height increases, leaving aside the fact that at ground level there may be other elements which could eventually slow down the wind speed, such as vegetation. This increase in the risk of overturning has caught the attention of several studies, which have been focused on the characterisation of the aerodynamic response to cross-winds of either road vehicles [14–19] or rolling stock [20–26] travelling on bridges.

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* Corresponding author.
*E-mail addresses:* s.avila@upm.es (S. Avila-Sanchez), oscar.lopez.garcia@upm.es (O. Lopez-Garcia), alvaro.cuerva@upm.es (A. Cuerva), j.meseguer@upm.es (J. Meseguer).

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One of the most effective ways to alleviate the adverse effects of cross-wind loads is by placing windbreaks (also named parapets) upstream the elements to be protected. Windbreaks have been and still are extensively studied because of their use in agriculture [27–30], wind-erosion control [31–33] and reduction of wind loading on civil engineering structures [34–37], amongst other applications. Traffic safety and comfort can also be improved by the use of such wind protection devices. Some efforts have been paid to analyse the effectiveness of parapets to protect trains and other vehicles from cross-wind effects [20,38–40]. Provided the parapet is high enough, experimental results show that very drastic reduction of the wind load coefficients on the train model can be obtained. Also experimental results existing in the literature evidence that the addition of eaves to the parapets improves the shelter effect of the windbreaks [20]. Unfortunately, these elements can induce modifications of the flow field that could lead to the appearance of additional undesirable wind loads on the railway overhead.

The flow around a bridge deck, either with or without parapets, is driven by flow separation. The flow separates at the upper windward edge of an empty bridge without wind barriers [20,41]. The flow reattachment position is influenced both by the wind incidence angle, as well as turbulence, i.e. for stronger freestream turbulence the flow reattaches closer to the bridge leading edge. The resulting shear layer can reattach on the bridge deck forming a recirculation bubble, provided the angle of incidence of the flow is small enough. A thinner wake downstream the bridge appears when the reattachment occurs, because a second flow separation occurs at the leeward edges. When the railway bridge is equipped with solid windbreaks, the flow separation takes place at the upper edge of the windbreak, and the vertical distance of the shear layer to the deck increases accordingly. The inclusion of eaves at the windbreak tip boosts this effect [41]. If the parapet is high enough, the resulting shear layer can impinge the catenary, increasing the turbulence intensity at the contact wire locations [42]. Scanlon and Oldroyd [9] pointed out that the increment of turbulence intensity (and the modification of the flow field in general) at the location of the contact wires, due to the presence of windbreaks, is of great interest in order to provide a more detailed description of the cable galloping phenomenon.

Over the past few decades several studies have been devoted to analyse the shelter efficiency of windbreaks and shelterbelts. In general, three different approaches have been adopted in order to characterise the shelter efficiency of windbreaks. The first approach consists on the characterisation of the effect induced on an obstacle downstream the fence, such as the wind tunnel analysis of the wind driven erosion on a triangular hill made of sand particles, described in [32], or the determination of the aerodynamic coefficients of a train model exposed to cross-flow conditions, presented in [43]. The second approach consists in quantifying the drag coefficient of the windbreak [44,45]. The third approach relies on the characterisation of the flow field downstream the windbreak. This flow field characterisation has been conducted either by means of full-scale measurements [30,46–48], either by tests in wind tunnel [49–53] or by means of computational simulations [31,53–58].

A large variety of experimental techniques has been used in order to characterise the flow properties downstream of the windbreaks. For instance, Cornelis and Gabriels [59] and Dierickx et al. [60] used full-scale measurements from vane probes installed at several locations, in order to determine the modification of the wind velocity field induced by the inclusion of a windbreak. Other full-scale experimental techniques include the use of cup and sonic anemometers [47,48,61]. With regard to wind tunnel testing, particle tracking velocimetry (PTV) [62], flow visualisation of the commencement of sand particle motion [32], hot-wire anemometry [46,63] and particle image velocimetry (PIV) [49,50,64–66] have been applied.

There exist some discrepancies concerning the sheltering efficiency between the different studies, because the wind velocity reduction and the turbulence intensity increase are directly related to both the windbreak design and the incoming flow characteristics. The flow properties downstream the windbreak are influenced by its porosity, shape, orientation and the distance to the obstacle. For a given windbreak height, the design parameter which is considered to have the main influence on the wind properties downstream the windbreak is the porosity, defined as the ratio of the open area of the windbreak to its frontal area. It is widely accepted that low porosity values produce higher wind velocity reductions close to the parapet, inside its wake, but also that the increment of turbulence intensity downstream the windbreak decreases as porosity increases [48–50,54]. Although low porosity fences produce larger mean wind speed reductions, the flow region affected by the windbreak may be smaller due to a stronger recirculation and a reduced size of the separation bubble.

In order to optimise the shelter effect provided by the windbreak design, a basic understanding on the basic flow patterns taking place upwind and downwind a two-dimensional windbreak may be useful. These flow patterns, already described by several authors [57,67,68], are schematized in Fig. 1. The flow in the region (A) is mainly driven by the undisturbed freestream velocity. The windbreak is idealised as a solid boundary that obstructs, and therefore displaces, the incoming flow (B). This flow is accelerated in the region immediately above the windbreak, close to the windbreak tip. The flow inside the wake downstream is decelerated by the windbreak. If there are no additional obstacles, this region is mixed with the outer flow, and the development of a new boundary layer is possible (E). Two interesting characteristics are pointed out in the conceptual sketch of the flow patterns. The first one, as described by Plate [67], is that solid windbreaks may lead to reverse flow regions in the mean velocity field and the appearance of a separation bubble (region G). The other one is associated to the appearance of small vortex-like structures (F) in a region referred by Speckart and Pardyjak [57] as the bleed flow.

Plate [67] pointed out that the optimisation of the windbreak arrangement based on a particular requirement needs input information from several sources, such as the aerodynamics of the windbreak. In the present work, the investigation is focused on the flow properties around the catenary contact wire of a railway bridge section. The main concern of most of the windbreak studies has been the determination of the flow structure in the sheltered region, induced by the presence of windbreaks located upstream the region under study. In consequence, there is no much information on the wind characteristics in downstream locations where catenary contact wires are typically located. Nevertheless, it is fair to mention that Kozmar et al. [64,65] studied by means of PIV technique in a wind tunnel, the characteristics of the flow above a model bridge section equipped with windbreaks at the leading edge. These authors reported an increment on the wind velocity with the windbreak porosity. Kwon et al. [39] focused on the design criteria in order to protect vehicles on an expressway. They provided a characterisation based on hot-wire anemometry of the shelter effect determined as the velocity magnitude reduction. Besides Kozmar et al. [64,65] and Kwon et al. [39], several authors have focused the interest on the effect induced by a single windbreak placed at the leading edge. For instance, Guo et al. [69] analysed the effect of the windbreak height and porosity on the aerodynamic coefficients of a static train model. He et al. [23] also included in their study the aerodynamic interference due to adjacent trains. He et al. [23] described that the separated flow from the top of a solid windbreak forms a trapped vortex on the deck

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