Journal of Wind Engineering & Industrial Aerodynamics 173 (2018) 79–90

Contents lists available at ScienceDirect

Journal of Wind Engineering & Industrial Aerodynamics

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

Solid barriers for windblown sand mitigation: Aerodynamic behavior and conceptual design guidelines

Luca Bruno [a,d,*], Davide Fransos [b,d], Andrea Lo Giudice [b,c,d]

[a] Politecnico di Torino, Department of Architecture and Design, Viale Mattioli 39, I-10125, Torino, Italy
[b] Optiflow Company, 160, Chemin de la Madrague-Ville, F-13015, Marseille, France
[c] Politecnico di Torino, Department of Mathematical Sciences "Giuseppe Luigi Lagrange", Corso Duca degli Abruzzi, 24, I-10129, Torino, Italy
[d] Windblown Sand Modeling and Mitigation Joint Research Group, Italy

ARTICLE INFO

Keywords:
Windblown sand
Mitigation measures
Solid barrier
Trapping efficiency
Design guidelines
Computational Wind Engineering

ABSTRACT

Protection from windblown-sand is one of the key engineering issues for construction and maintenance of human infrastructures in arid environments. In the last century, several barriers with different shapes have been proposed in order to overcome this problem, but literature lacks of a systematic performance quantitative analysis, and the key geometric parameters that promote sedimentation have not been yet recognized. A deep understanding of the aerodynamics effects of sand barrier on the flow is an unavoidable step to achieve these objectives. The present computational study aims to comparatively analyze different kinds of windblown sand mitigation solid barriers, clarify their working principles, extract from the aerodynamics analysis key geometrical features of the barriers and relate them to the sand trapping performances. Approximated metrics for performance assessment are introduced using aerodynamic parameters. The performances of an innovative solid barrier and the ones of commonly used solid barriers are compared in terms of these metrics. The effects of incoming wind velocity profiles on sand trapping performances are evaluated as well. An empirical dimensionless performance estimator is proposed and used to provide general design guidelines.

1. Introduction

The engineering interest about windblown sand is dictated by the harmful interactions that sand can have with a number of human infrastructures in arid environments (Middleton and Sternberg, 2013), such as pipelines (Kerr and Nigra, 1952) and industrial facilities (Alghamdi and Al-Kahtani, 2005), farms (Stigter et al., 2002), towns (Zhang et al., 2007) or single buildings (Bofah et al., 1991), roads (Redding and Lord, 1981) and railways. In particular, the wind-induced accumulation of sand poses key challenges for railways crossing deserts and arid regions (e.g. Zhang et al., 1995, 2010; Zakeri and Forghani, 2012; Cheng and Xue, 2014; Cheng et al., 2015). Strategies to overcome the problem usually go under the name of Sand Mitigation (SM). Most of SMs are intended to interrupt the sand transport process and to promote its sedimentation away from human infrastructures to be protected. The devices built to put in place this strategy (Sand Mitigation Measures, SMMs) are located along the windblown sand path upwind the infrastructure to be protected (Fig. 1).

Such devices range from stabilized sand berms and ditches to porous fences and solid barriers, or different combinations of them.

Porous fences have been widely investigated in the scientific literature since the early studies at the beginning of the 20th century. The research activity about fences has been recently reviewed with respect to both wind loads (Giannoulis et al., 2012), aerodynamics (Hong et al., 2015), and induced morphodynamics (Li and Sherman, 2015). Very briefly, the porosity ratio and its distribution is commonly considered the most important single parameter driving the design and controlling the performance of a sand fence of a given height, and for a given incoming wind.

Conversely, to our best knowledge, scientific studies on the aerodynamics and morphodynamics of windblown sand solid barriers, i.e. having null porosity, are surprisingly scarce. The aerodynamics of a solid straight vertical wall has been investigated by Baines (1963), Good and Joubert (1968) and Letchford and Holmes (1994) with wind tunnel tests in nominal 2D conditions. In particular, Baines (1963) shows that the local wind pattern around it is characterized by a large reversed flow

* Corresponding author. Politecnico di Torino, Department of Architecture and Design, Viale Mattioli 39, I-10125, Torino, Italy.
E-mail address: luca.bruno@polito.it (L. Bruno).
URL: http://www.polito.it/wsmm

https://doi.org/10.1016/j.jweia.2017.12.005
Received 9 June 2017; Received in revised form 29 October 2017; Accepted 5 December 2017

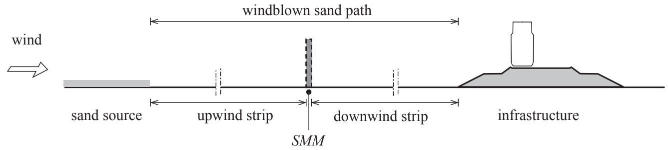

Fig. 1. Conceptual scheme of the sand source, SMM and infrastructure: cross section.

region in the wake of the barrier and by a stable clockwise eddy with horizontal axis along the upwind front of the wall below the stagnation point (Fig. 2-a).

This upwind eddy is the distinctive flow structure with respect to the flow pattern around a porous fence (e.g. Dong et al., 2007; - Fig. 4), the latter depending on porosity value. In particular, from medium to high porosity, it is characterized by the absence of the stagnation point and by the sole reversed region in the wake. According to Baines (1963), the upwind eddy results from the curvature of the incoming velocity profile, while it vanishes for a constant incoming wind field (Fig. 2-b).

In a morphodynamic perspective, solid barriers are usually adopted as a limit term of reference in the performance assessment of fences having various porosity ratios and distribution, e.g. Cornelis and Gabriels (2005). On one hand, it is widely accepted that fences with an optimal porosity of around 40–50% (e.g. Savage and Woodhouse, 1968; Bofah and Al-Hinai, 1986) have a sand trapping efficiency (defined as the maximum volume of accumulated sand per fence unit length) higher than a solid barrier. On the other hand, the distribution of the accumulated sand around porous fences and solid barrier is qualitatively different. Hotta and Horikawa (1991) show that sand mainly accumulates in the upwind strip of a solid straight vertical wall, while porous fences involve sedimentation on both strips, and have more sand deposited in the downwind one (Fig. 3).

To our best knowledge, existing solid barriers having different shapes with respect to the straight vertical wall are scarcely investigated in scientific literature so far. Consequently, the parameters driving their design and controlling their performance are unclear. As a consequence of this poor knowledge, designers and inventors have not been adequately supported in devising new SMMs. A 4 m-high straight vertical wall has been proposed as a SMM in the preliminary design of the Segment 1 of the Oman National Railway Network (Italferr, 2014). A 1.5 m-high straight vertical wall has been recently tested in situ along the Mecca-Medina high speed railway in Saudi Arabia (Mendez, 2016), showing insufficient performances. Solid barriers with other geometries have been patented as MMs for different kind of multiphase flows, but their qualitative behavior as mitigation measures has been merely conjectured by the inventors, without rigorous scientific investigation. Murakami and Sakamoto (2001) proposed a vertical barrier with leeward curved free end to shelter highways against windblown snow. Analogously, Guangyong and Peng (2012) patented a leeward inclined barrier with rounded free end to avoid windblown sand sedimentation along railways. Pettus Newell (1903) patented a λ-shaped wood barrier with upwind concavity in order to promote the windblown sand sedimentation upwind the barrier for railway applications. Analogously, Pensa et al. (1990) patented a λ-shaped precast r.c. barrier to be used as SMM for agroforestry applications. Very recently, Bruno et al. (2015) have proposed a novel solid barriers called *Shield for Sand* and patented by Politecnico di Torino. It is equipped with an ad hoc conceived windward concave deflector aimed at making the extent of the upwind eddy and the sand trapping efficiency as large as possible.

In short, four main comments may summarize the above introductory review:

- the results of Hotta and Horikawa (1991) are qualitatively consistent with the wind patterns found by Baines (1963): sedimentation around porous fences is mainly driven by the wind velocity reduction around both surfaces and, to a minor extent, by the wake recirculation region; sedimentation around solid straight vertical wall is conjectured to be mainly driven by the upwind eddy and related reversed flow along the upwind strip;
- generally speaking, porous fences are advisable in dune-building applications, when the fast formation of a bell-shaped dune is pursued and periodic sand removal is not required. Conversely, solid barriers should be preferred as SMM around infrastructures because they involve sedimentation in the upwind strip only, prevent the infrastructure corridor contamination, and allow a safer and cheaper sand removal;
- the quantitative assessment of the effective performance of solid barriers other than the straight vertical wall is needed by infrastructure designers to properly select the most suited design solutions, but it remains an open issue at the present state of the art;
- general design guidelines based on sound aerodynamic principles are needed to inspire the concept of optimal forms for solid barriers.

The present study aims at addressing these open issues by means of a comparative computational study on the aerodynamic behavior of the solid barriers reviewed above. In Section 2 the modeling and computational approach are briefly recalled. The solid barriers selected for the comparative analysis are described in Section 3 together with the far-field wind flow conditions adopted. The results of the analysis are provided in Section 4, while some guidelines for the barrier aerodynamic

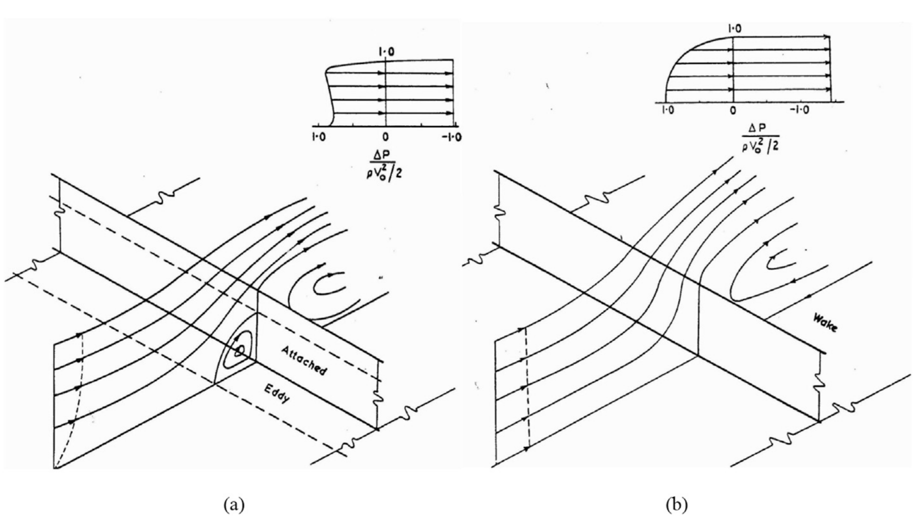

Fig. 2. Flow patterns around a solid straight vertical wall: log-type (a) and constant (b) incoming velocity profile (Reprinted from Baines, 1963).