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Review

# Aerodynamics and morphodynamics of sand fences: A review

Bailiang Li [a,*], Douglas J. Sherman [b]

[a] Department of Environmental Science, Xi'an Jiaotong-Liverpool University, Suzhou, Jiangsu 215123, China
[b] Department of Geography, University of Alabama, Tuscaloosa, AL 35487, USA

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ABSTRACT

This paper reviews literature on the aerodynamics and morphodynamics of sand fences. We consider both wind fences for reducing wind erosion, and sand-trapping fences for controlling sand deposition. There has been substantial trial-and-error research based upon installations of sand fences, but only limited research on the fence and site attributes that provide the main aerodynamic and morphodynamic controls of interactions between aeolian systems and the fences. Such attributes include: fence porosity, height, length, width, opening size and geometry, porosity distribution, and external factors such as incoming flow characteristics, roughness length, atmospheric stability, grain size and local landform change. Considerations for the optimal design for both wind fences and sand-trapping fences are presented.



**Contents**



* Corresponding author.

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## 1. Introduction

Sand fences are artificial structures used to control the location and rate of aeolian erosion or deposition. Such fences are deployed extensively in deserts, on beaches, or near some man-made structures where the need to control aeolian sedimentation is recognized. Using fences as part of a management strategy is attractive because they are usually effective, inexpensive and their effects can be seen quickly (Grafals-Soto and Nordstrom, 2009). In arid regions, fences are used to reduce sand deposition into a target system (e.g., roads, railways) or to reduce wind erosion in an area behind a fence (Dong et al., 2004, 2007). In coastal areas, fences have three major applications (c.f. Kerr and Nigra, 1952; Hotta et al., 1987; Grafals-Soto and Nordstrom, 2009). The first is trapping sand to initiate foredune development perpendicular to wind (Snyder and Pinet, 1981; Hotta and Horikawa, 1990; Miller et al., 2001). The second, in occasional cases, is to reorient the wind to intensify scouring tangent to the prevailing wind (McLaughlin and Brown, 1942). The third application is to reduce or prevent onshore sand drift that would bury cultural or ecological features (Sherman and Nordstrom, 1994; Jackson and Nordstrom, 2011). If the purpose of a fence is to reduce wind speed and thereby limit aeolian erosion and protect objects in a downwind shelter zone, then the structure is typically referred to as a wind fence. When the role of a fence is trapping sand, it is usually referred to as a sand, or sand-trapping fence. The aerodynamics and morphodynamics of both types of fences are discussed in this review.

Fences are constructed using materials such as concrete, metal, plastic, wood, stone, sod or vegetation (Martin, 1887; Primack, 1969; Hewes, 1981; Raitz, 1995; Pickard, 2005; VerCauteren et al., 2006). Some common design-types include upright, horizontal, griddled, holed-plank, and wind-screened fences (c.f. Fig. 1 in Dong et al., 2007). Fences made of artificial, rigid materials are usually thin and small; essentially 2-D structures (e.g. Barr, 1974; CERC, 1977; Alghamdi and Al-Kahtani, 2005; Khalil, 2008). There are also some 3-D structures formed with vegetation or brush (e.g. Hotta and Horikawa, 1996; Anthony et al., 2007), or, at a larger scale, by one or more rows of shrubs or trees. The latter are usually called windbreaks or shelterbelts (e.g. Stipho, 1992; Mohammed et al., 1996; Cornelis and Gabriels, 2005). Shelterbelts can extend up to several hundred kilometers in length (Wang and Zhou, 2003), and their shape and density can be adjusted through time, depending on the wind regime. In this review we will focus on rigid fences, even though brush fences and shelterbelts play important roles in controlling local wind regimes and sediment transport in many locations, especially in arid environments.

The aerodynamics and morphodynamics of a fence depend on the geometry of the fence design, with the elements of height, length, width (these characteristics are illustrated in Fig. 1), porosity, opening size/distribution/geometry, and orientation relative to the wind being most important. Fence (or optical) porosity, $\beta$, is the degree of permeability of a fence, or the ratio of a fence's open area to its total area. It is commonly considered the most important single parameter controlling the performance of a sand fence of a given height, and usually reported as a percentage of open area (Bean et al., 1975).

The influence of a fence on a local wind regime will also depend on environmental conditions that include incoming flow conditions, local topography, and sedimentology. The aerodynamics of these geometries and their influence on sand transport and landform change are reviewed with the intent of proposing optimal fence designs for different purposes. For more general reviews of near-surface aerodynamics or aeolian sand transport, the reader is directed to, for example, Kok et al. (2012), Bauer (2013), or Ellis and Sherman (2013).

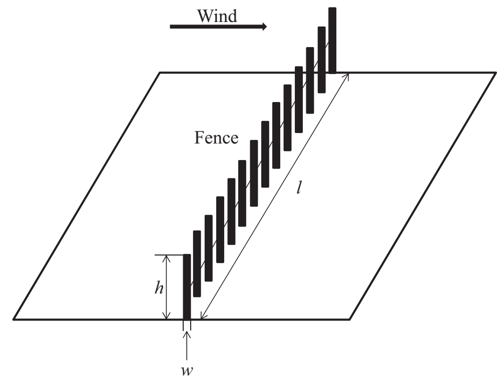


**Fig. 1.** Definitions of wind fence height *h*, length *l* and width *w*.

## 2. Aerodynamics and morphodynamics of sand fences

Formal aerodynamic research on sand fences can be traced back at least to the beginning of the 20th century (Bates, 1911), when it was realized that the rational design of wind fences required better understanding of the dynamics of air flow over, through, and around the fences. However, it was not until the 1930s that researchers began to study the aerodynamics experimentally (Finney, 1934). Since then, a number of experiments in the field, but mainly in the laboratory, have aimed to characterize the sheltering and sand trapping effects of fences. More recently, we have seen the development of a number of theoretical and numerical models of these effects. In this section we review studies of airflow in the vicinity of sand fences, the effects on sand transport, the controls of fence geometry on airflow disturbance, sand transport and dune development, and key elements for modeling those effects. We will not address, except as relevant to aerodynamic and morphodynamic impacts, the many empirical studies involving sand fence installation and monitoring efforts (e.g. CERC, 1977; Nordstrom and McCluskey, 1985; Stipho, 1992; Miller et al., 2001; Khalil, 2008; Grafals-Soto, 2010). We note that there have been few controlled fence experiments with sand transport, presumably because of the complexity of two phase interactions between wind and sand.

### 2.1. Airflow structure, sand transport regimes and dune growth

Much of the work concerning the interaction of sand fences with wind fields and sand transport has addressed the formation of zones of wind modification in the vicinity of a fence and the classification of resulting transport regimes. The categorization of flow zones is based upon the distribution of characteristic airflow structures. The characterization of transport regimes has been based upon the interaction of flow within the flow zones and, mainly, the resulting changes in the magnitude or direction of sand transport.

#### 2.1.1. Airflow structure

Most early studies of airflow regimes were conducted around shelterbelts to examine the degree and patterns of wind reduction that they caused (Bates, 1911; Naegëli, 1943; Kreutz, 1952). The airflow structure could not be measured because of the large scales involved and a general lack of convenient instrumentation. It was not until the 1930s that wind tunnels were first used to measure and quantify the airflow around a fence (Finney, 1934). Since then, there have been many detailed wind-tunnel experiments (Gloyne, 1954; Dyunin, 1964; Plate, 1971; Raine and Stevenson, 1977; Judd et al., 1996; Dong et al., 2007).