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Field measurements of shelter efficacy for installed wind fences in the open coal yard

X.C. Cong [a,*], H.B. Du [b], S.T. Peng [b], M.X. Dai [b]

[a] Shandong Provincial Key Laboratory of Civil Engineering Disaster Prevention and Mitigation, Shandong University of Science and Technology, Qingdao 266510, China

[b] Laboratory of Environmental Protection in Water Transport Engineering, Tianjin Research Institute of Water Transport Engineering, Tianjin 300346, China

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ABSTRACT

To investigate the shelter effect of porous fences with 40% porosity installed along two sides of Yard 1 in Qinghuangdao Port, the full scale field measurement campaigns are carried out in this study. A time series of the velocity signals are recorded. It is found that instantaneous velocities and turbulent intensity within the yard are largely reduced. The shelter effect produced by the fences has been analyzed in terms of wind reduction ratio and time-average velocity reduction profiles are obtained among the horizontal and longitudinal directions within the yard. The actual protection distance caused by the fence and stored piles themselves may be extended up to 6–7th consecutively stockpiles. Then, the value of average wind reduction coefficient (ζ) is obtained to evaluate the fence sheltering under various wind incidents. It is calculated that the average wind reduction ratio in the whole year is about 51.5% at the 6.0 m measurement height from the ground. In addition, the particle concentration measurements are conducted to ascertain the fences prevention of dust erosion. The results reveal that about 50–80% of total suspension particles are entrapped by the fence and the emission levels of the reference location satisfy the environmental regulations after the fences were installed along the yard boundary.

1. Introduction

Wind fences are common devices to improve windy climatic conditions in a range of applications such as preventing snow drift, soil erosion and pollutant dispersion. As an artificial barrier to reduce the speed of oncoming winds, porous fences are widely used in coastal, arid and cold areas. For example, a large amount of bulky materials (e.g. coal and ore powders) are stored and transported in large open yards of harbor areas. Exposed to variable winds, these materials are subject to wind erosion which causes a loss of raw materials and serious environmental problems. To reduce atmospheric dispersion of wind-blown dust particle, one applicable methodology of decreasing emissions in industrial sites is to use wind fences (Borges and Viegas, 1988; Dong et al., 2007). In 2009, the huge porous fences along two sides of coal Yard 1 were erected in Qinhuangdao Port of Hebei Province, China. It is the biggest engineering fence in Asia so far.

The primary benefit of porous fences is the reduction of wind velocity within a certain distance. Since the middle of the last century, considerable efforts focused on the effectiveness of fences and airflow mechanism around porous fences. The impacts of fence's geometrical features (such as optimal porosity, fence height, permeable-hole configuration and arrangement, etc.) on airflow structure are mostly investigated. Raine and Stevenson (1977) demonstrated in their tests that a fence with a porosity of 0.2 gave the best overall reduction in leeward mean velocity. Perera (1981) found that the Reynolds shear stress and turbulent kinetic energy were strong behind the fence when the porosity was less than 0.3. Lee and Park (1998, 1999) measured the velocity field and surface pressure distributions and found that the wind fence of porosity $\varepsilon = 40\%$ was the most effective for reducing pressure fluctuations on the prism surface. Lee et al.'s (2002) wind tunnel results showed that a porous wind fence with a porosity of 0.3 was the most effective for abating windblown sand particles. Dong et al. (2006) indicated that fences with porosities of 0.3–0.5 had the maximum threshold wind velocity (i.e., the wind velocity required to initiate particle movement) and were the most suitable for controlling wind erosion. Dong et al. (2007) measured that the reattachment distance along downstream could extend to 8–16 times of the fence height when the fence porosity was less than 0.3.

Moreover, several previous studies have investigated the interception function of fences that captures the eroded particle drift and decreases dust emissions into the air. Raupach et al. (2001) and Ucar and Hall (2001) experimental results showed that spray drifts were reduced up to 80–90% immediately behind a porous

* Corresponding author.
E-mail address: congxiaochun@126.com (X.C. Cong).

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fence by using fluorometric counting methods. Lee et al. (2002) found that the total suspension particles (TSP) were reduced 70–80% when the porous wind fences were installed around the Kwang–Yang open storage yard.

From an engineering point of view, it is necessary to verify the shelter efficiency of installed porous fences in full-scale observations after installing wind fences. This study, taking an example of the installed porous fences in Yard 1 of Qinhuangdao Port, carries out real field campaigns. The airflow over the coal piles around the fences is measured and the shelter effect of constructed porous fences is evaluated. Moreover, the function of interception eroded particle emission is investigated by measuring the TSP concentrations. These data provide an understanding of the aerodynamics of wind fences in the real-world view.

2. Experiment methods and instruments

2.1. General descriptions

Qinhuangdao Port is located in northeast of Hebei Province. Its geographically position is 39°54′–39°57′, and 119°34′–119°44′ in the north latitude and east longitude, respectively. The port is mainly made up of three coal yards named as Yards 1–3. Here, Yard 1 is of stored area of 660,000 m^2 and 56 stockpiles are arranged to be piled with seven rows and eight columns. These stacks are stored consecutively with an identical geometry sharp.

According to the meteorological observation of wind data from 2007 to 2009, the dominant wind incident is north-eastern with 15.44% frequency, followed by east incident with 13.41% frequency. Meanwhile, yearly mean wind speed is about 2.03 m $s^{-1}$and the average speed of the dominant wind direction is 1.94 m s^{-1}. The seasonally averaged wind speed rose is presented in Fig. 1.

As Qinhuangdao Port is located at the seaside of Bohai Bay, coal dusts of open storage yards are blown by strong wind and local gusts, especially in the summer stormy season. Taking the yard's topographic and meteorological factors into account, the porous fences were constructed in 2009. The fences were installed along the eastern and southern boundaries of Yard 1with the total length of about 2071 m. The height of the fences is 23 m, higher than average height of the coal piles (17 m). The fences are stretched as a single-layer panel made of galvanized metal plates. The photograph of the porous fences installed in Yard 1 is shown in Fig. 2a. The porous plates are 1.2 mm in thickness and folded with an angle of 40°, as shown in Fig. 2b. The homogeneous holes are distributed to make up the porosity $\varepsilon=40\%$. Lee and Park (1999, 2000, 2001), Lee et al. (2002) and Park and Lee (2003) performed a series of wind-tunnel experiments to determine the wind erosion characteristics of open coal piles. They found a porosity of around 30–50% that resulted in the maximum attenuation of the mean wind velocity as well as suppression of intense turbulent characteristics on the pile model surface. Santiago et al. (2007) concluded that the windbreaks recommended to protect piles of materials stored in an open location were porous fences with porosity close to 0.35 because this fence could maximally reduce peak velocity at large distance downward. Hence, the homogeneous distributed porosity $\varepsilon=40\%$ is determined for the installed fences. Their resistance measurements and geometrical parameters are measured in our previous study (Cong et al., 2011).

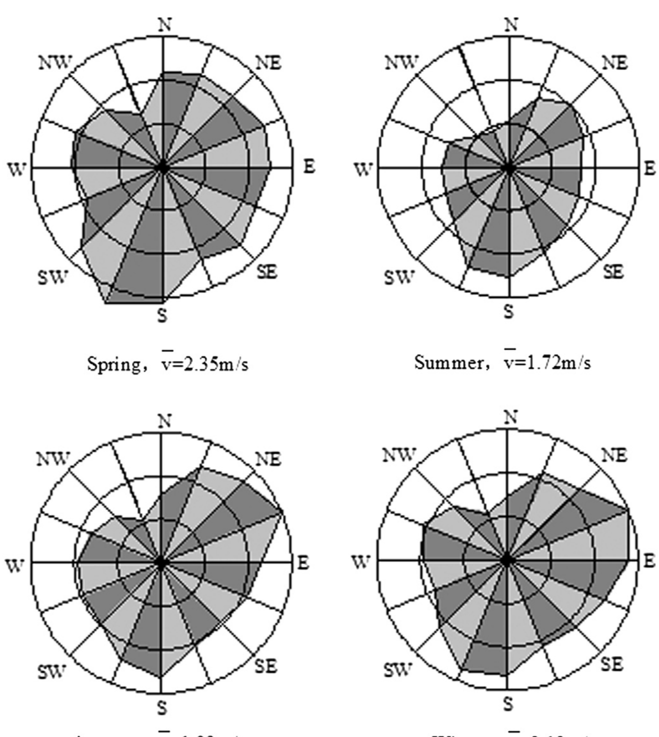

Fig. 1. Seasonally averaged wind speed rose during the year of 2007–2009.

2.2. Experiment method and instruments

To ascertain effectiveness of the porous fences installed around the yard, the real field measurements are carried out. The whole campaigns are comprised of two measurement stages from March 26 to 31, 2010, named Campaign I and from June 1 to 6, 2011, called Campaign II.

In the Campaign I, 16 sites are located within the yard and an undisturbed reference location is positioned outside of the yard (Fig. 3a). In theoretical viewpoint, the reference anemometer should be always placed windward of the fence. However, the natural wind direction is instantaneously variable in real situation. So it is required that the reference anemometer can measure the far upstream undisturbed wind at all time. In this study, the location of reference point is elaborately chosen. And its site is located at 10 m height with about 25*H* distance from the east fence and 30*H* distance from the south fence. This location is far enough from the fences to guarantee for the oncoming wind with the initial undisturbed characteristics. The measurement points cover the whole area of the yard. For clear illustration, the velocity measurement locations are specified with the row and column numbers. For example, locations 1–4 are made up of Row 1; whereas location 4, 8, 12 and 16 constitute Column 1. At each wind speed measurement location (including the reference point of oncoming wind), a portable anemometer (model ZDR-1F) is employed with a crane head attached at a maximum height of 10 m above the ground. All monitoring instruments are started up almost synchronously. The wind speed data are monitored every 10 s and average values are recorded every 2 min in the experimental field. The 16 measurement points are repeatedly monitored at the vertical height of 4, 6 and 8 m from the ground.

In the Campaign II, six sampling sites are arranged to monitor dust concentrations (Fig. 3b). Locations T1–T3 are located inside the yard, whereas locations T4–T6 are positioned outside the yard. Herein, Point T6 (about 32*H* distance from the east fence and 34*H* distance from the south fence) is located in the residential zone and regarded as the reference site for background particle concentration. At each particle sampling location, the medium volume flow TSP samplers (model TH-150) are used with PM_{10}–$PM_{2.5}$ combination cutters. Before sampling, the instruments are set as calibration flow rate. Meanwhile, the filter membranes for sampling are numbered and weighted in advance. After the end of each measurement, the used filter membranes are kept with