Aeolian Research 35 (2018) 39–46

Contents lists available at ScienceDirect

Aeolian Research

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

Wind speed characteristics and blown sand flux over a gravel surface in a compact wind tunnel

Jiaqi Liu*, Reiji Kimura

Arid Land Research Center, Tottori University, Hamasaka 1390, Tottori 680-0001, Japan

ARTICLE INFO

Keywords:
Arid regions
Boundary layer
Blown sand flux
Piezoelectric blown sand meter
Roughness length

ABSTRACT

We investigated the influence of gravel coverage on roughness length and blown sand flux in a compact wind tunnel equipped with a turbulence generator and a piezoelectric blown sand meter. At gravel coverages from 5% to 15%, roughness length increased with increasing coverage. However, at coverages of 20% or greater, roughness length reverted to its value at 0% coverage. At the lowest wind speed of 6 m s^{-1}, blown sand was fully trapped at gravel coverages of 15% or greater; however, coverage affected sand flux little at wind speeds of 8 and 9 m s^{-1} and had no effect at a wind speed of 10 m s^{-1}. The increase in roughness length with gravel coverages from 5% to 15% corresponded to a decreased blown sand flux at heights less than 8 cm. However, at 8-cm height, a greatly decreased roughness length at higher gravel coverages (20%–30%) corresponded to a notable increase in blown sand flux, a change we attribute to aerodynamic smoothing.

1. Introduction

Mongolia is one of the most important source regions for Asian dust (Bian et al., 2011; Wesche and Retzer, 2005) and is responsible for about half of the total production of Asian dust (Zhang et al., 2003; Tan et al., 2012). According to observations in Mongolia, dust storms occur mainly in spring (March to May) and last about 3–6 h on average (Natsagdorj et al., 2003). As dust storms can cause serious environmental impacts on human and livestock health, economic activities, air pollution, and soil erosion in Mongolia, development of a dust hazard map and early warning or monitoring systems is urgently needed (Kimura, 2016).

About 70% of Mongolian dust storms occur under dry soil conditions (Natsagdorj et al., 2003). A considerable part of Mongolia consists of dry soil in desert plains, especially the Gobi Desert. In this area, dust storms are frequent and severe (Shao and Dong, 2006), reaching an average of 34 dust storm days per year at Zamiin Uud in the southern part of the Gobi Desert (Middleton, 1991). These sparsely vegetated areas are typically covered with fine gravel, the origin of the name "Gobi." Although gravel mulch is known as an effective measure to stabilize surfaces, inhibit wind erosion, and protect the underlying fine material (Liu et al., 2011; Tan et al., 2013b; Zhang et al., 2014), there are few reports on the interaction of strong winds with the relatively fine-grained gravel of the Gobi Desert.

Wind-blown sand is a mixed flow of gas and solid particles (Zinamenski, 1960) that originates in the interaction of air and sandy surfaces on two different physical media (Almeida et al., 2006). Because the flow of wind-blown sand can aggravate the process of land desertification, it is important to better analyze the physical relationships between vertical wind speed profiles and the flux of sand blown from different surfaces, and thus to find ways to reduce the damage caused by sand movement. Studies of the flow of wind-blown sand and the factors affecting it are indispensable (Dong et al., 2003).

Parameters related to the vertical wind speed profile, such as friction coefficient, roughness length, and zero displacement height, have been developed to express the responses of airflow to different ground surfaces and the presence of obstacles (Dong et al., 2002). Over smooth ground surfaces, the change in wind speed with height follows a logarithmic relation, but above gravel surfaces, this relationship does not hold in the boundary layer below a specific height. The influence of surface roughness on the boundary layer has therefore been a subject of interest (Schlichting et al., 1955; Neuman, 1998; Zhang et al., 2004).

The physics of blown sand under the influence of surface roughness is related not only to the vertical distribution of wind speed, but also to the vertical distribution of the flow of wind-blown sand (Wu, 2003). Recent studies have investigated the hydrodynamic characteristics of blown sand in the boundary layer over smooth ground surfaces and have also described the flux profiles of different sand sizes at different free-stream wind velocities. Some researchers have proposed that the distribution of blown sand fluxes with height can be expressed by an

* Corresponding author.
E-mail address: ryuu731@tottori-u.ac.jp (J. Liu).

https://doi.org/10.1016/j.aeolia.2018.09.005
Received 10 May 2018; Received in revised form 7 September 2018; Accepted 26 September 2018
1875-9637/ © 2018 Elsevier B.V. All rights reserved.

exponential function (Liu and Dong, 2004). On the other hand, Liu et al. (2011) and Tan et al. (2013a) used a mobile wind tunnel test in the Mogao Grottoes region, China, to show that gravel beds can reduce sand transport, the effect increasing with gravel size. This experimental result has inspired the construction of artificial gravel surfaces to reduce damages from blown sand fluxes in that region (Tan et al., 2013b, 2016; Zhang et al., 2014). However, the gravel in that experiment was coarse grained (30 mm), whereas the Gobi Desert of Mongolia features fine-grained gravel. Thus, the wind speed profiles and blown sand fluxes associated with the fine-grained gravel of southern Mongolia are imperfectly known (Dong et al., 2002).

In particular, quantitative research into the vertical distribution of blown sand is hampered by the lack of a wind tunnel that can realistically model the atmospheric boundary layer. Also, measurements of blown sand flux that rely on sand traps are difficult for reasons including differences in trapping efficiencies with height, the length of time needed to trap meaningful amounts of sands, and the fact that only average data can be obtained for blown sand flux (Hotta and Horikawa, 1993).

In this study, we compared the influence of gravel coverage on the aerodynamic characteristics of the experimental wind field and the flux and distribution of blown sand by using a compact wind tunnel we recently developed (Liu and Kimura, 2017a,b) and a piezoelectric meter to characterize blown sand flux.

2. Experimental method

2.1. Wind tunnel and piezoelectric blown sand meter

The compact wind tunnel used in this study (Liu and Kimura, 2017a,b) consisted of a blower, a rectifying space, and an observation space (Fig. 1). The wind tunnel was 8.25 m long and had a cross section measuring 0.8 m × 0.5 m. The sides and ceiling of the rectifying space (3.6 m long) and the observation space (1.8 m long) were made of acrylic panels 8 cm thick. An inverter with a maximum output of 1.5 kW allowed the operator to specify wind speeds up to 12 m s^{-1}. A honeycomb screen with hexagonal openings, placed in front of the fan, served as a flow straightener.

The device used spires and roughness blocks to control turbulent flow and could achieve a flow with properties similar to the atmospheric boundary layer within a relatively short rectifying space (Fig. 2). The dimensions of the trapezoidal spires and roughness blocks were calculated from the empirical formulas determined by Irwin (1981). We then modified the heights of the spires and the widths of their bases to adjust the height of the upper boundary layer. As a result, the device could produce a boundary layer 34 cm thick within the short rectifying distance of 3.6 m, and the use of trapezoidal spires enabled us to generate a thick boundary layer and achieve an increased roughness length of 0.01 cm at the same time. The lower boundary layer was also modified by adjusting the spatial density of roughness blocks and the number of trapezoidal spires to obtain a wind velocity profile that was uniform in the horizontal direction. As a result, the device could produce an approximately uniform wind speed (varying by ± 0.01 m s^{-1} at a wind speed of 8 m s^{-1}) through the observation space (Liu and Kimura, 2017b).

The instrument for measuring blown sand was a ceramic sensor that used a piezoelectric transducer in combination with high-precision ultrasonic sensors to count the sand particles striking the sensor (Udo, 2008). A cone-type resonator with a diameter of 6.5 mm mounted on the sensor portion of the piezoelectric transducer made it feasible to count blown sand grains with high accuracy. That is, a sand grain hitting the surface of the resonator generated a clear electrical signal, from which the number of sand particles could be determined. The short response time of this signal, 0.001 s or less, made it feasible to count blown sand grains with high accuracy (Hosaka et al., 2004) (Fig. 3).

2.2. Measurement of wind speed characteristics

To measure the wind speed characteristics, the floor of the wind tunnel was covered with a wooden board coated with sand (Tottori dune sand) from the rectifying space to the observation space. The sand served to prevent damage to the anemometer caused by the impact of blown sand and to maintain a consistent surface roughness condition.

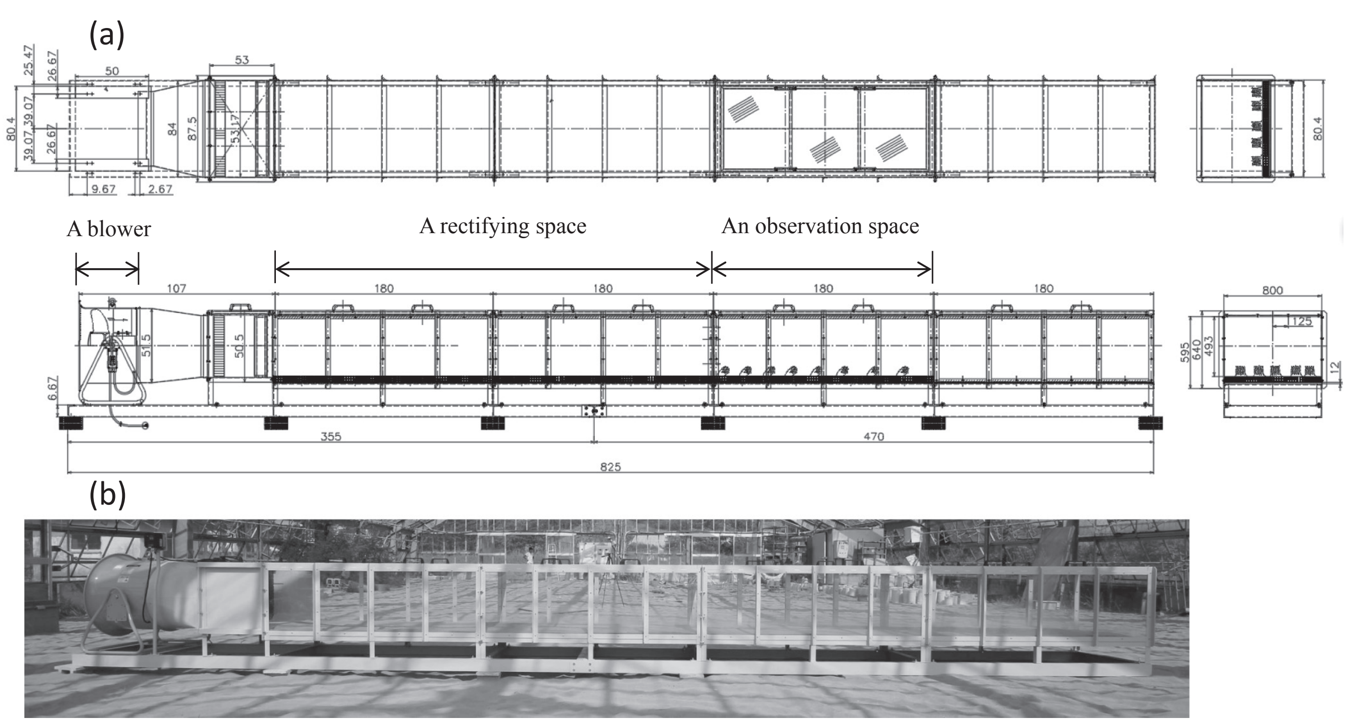

Fig. 1. Schematic diagram and photo of the wind tunnel used in this study.

Download English Version:

https://daneshyari.com/en/article/11028529

Download Persian Version:

https://daneshyari.com/article/11028529

Daneshyari.com