Geomorphology 106 (2009) 253–260

Contents lists available at ScienceDirect

Geomorphology

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

Sidewall effects of a wind tunnel on wind velocity and mass flux in aeolian sand transport

D.J. Feng, Z.S. Li, J.R. Ni *

Department of Environmental Engineering, Peking University, the Key Laboratory of Water and Sediment Sciences, Ministry of Education, Beijing 100871, China

ARTICLE INFO

Article history:
Received 17 January 2008
Received in revised form 5 November 2008
Accepted 10 November 2008
Available online 19 November 2008

Keywords:
Aeolian transport
Wind tunnel
Sidewall effects
Wind velocity
Mass flux

ABSTRACT

The sidewall effects of a wind tunnel on aeolian sand transport were investigated experimentally. A wind tunnel was used to conduct the experiments with a given channel height of 120 cm and varying widths (B) of 40, 60, 80, 100 and 120 cm. Both vertical profiles of wind velocity and sand mass flux were measured at different locations across the test section. The results show that the wind velocity with saltation first increases and then decreases to a minimum, from the sidewall to the central line of the wind tunnel. The discrepancy among wind velocities at different locations of the transverse section decreases with decreasing tunnel width. The wind friction velocity across the wind tunnel floor, with the exception of the region closest to the sidewalls, does not deviate strongly in wide wind tunnels from that along the central line, whereas it does vary in narrow tunnels. The sand mass fluxes, with the exception of some near-bed regions, are larger along the central line of the wind tunnel than they are at the quarter width location from the sidewall. Unlikely previously reported results, the dimensionless sand transport rate, $Qg/(\rho u_*^3)$ (where Q is the total sand transport rate, g is the gravitational acceleration constant, ρ is the air density, and u_* is the wind friction velocity), first decreases and then increases with the dimensionless friction velocity, u_*/u_{*t} (where u_{*t} is the threshold friction velocity). The above differences may be attributed to the sidewall effects of the wind tunnel. A dimensionless parameter, $F_B = u_*/(gB)^{1/2}$, is defined to reflect the sidewall effects on aeolian sand transport. The flows with F_B of 0.33 or less may be free from the sidewall effects of the wind tunnel and can ensure accurate saltation tunnel simulation.

1. Introduction

The wind tunnel is a very useful tool for investigating aeolian sand transport as it has advantages over field test, allowing controlled experimental conditions such as wind speed and duration. Wind tunnel studies, beginning with Bagnold (1941) and continuing in numerous investigations, have provided fundamental understanding of the physics of wind-blown sand (Lancaster, 1996), including sand grain trajectory (White and Schulz, 1977), saltation threshold (Iversen and White, 1982), and mass transport (Iversen and Rasmussen, 1999). However, compared with actual field situations, it is possible that the airflow accompanying the saltation of sand particles may be distorted in wind tunnels.

In aeolian studies, it is important to ensure that a thick boundary layer is fully developed so that the majority of the saltating particles in the wind tunnel are exposed to wind conditions similar to those in an atmospheric surface layer. In a wind tunnel, the boundary layer builds downstream from the entryway at a very slow rate. The exact shape of this layer and its transition to a free flow condition above depend on several things (White, 1991).

The wind tunnel dimension is one of the major factors that determine the development of the boundary layer and also if a resultant choked saltation flow will occur. In small wind tunnels, choked saltation may occur and lead to blockage of the air flow and alteration of both the particle flux and the velocity profiles (Butterfield, 1998). Owen and Gillette (1985) have been recognized as pioneers in the study of wind tunnel constraints on airflow with saltation. They analyzed variations in the friction speed as a function of the downstream position, and proposed that the flows with Froude numbers less than 20 should be free of facility constraints imposed on saltation. White and Mounla (1991) also carried out an experimental study of Froude number effect on wind tunnel saltation, and found that the optimum minimum entrance length for a wind tunnel was 25δ (where δ is the boundary layer height). A minimum tunnel length-to-height ratio of 5 and the flows with Froude numbers of 10 or less were suggested to ensure accurate tunnel experiments with saltation (White and Mounla, 1991). Neuman and Maljaars (1997) reported that Froude numbers at high wind velocities exceeded the conservative limit of 10 suggested by White and Mounla (1991) for an equilibrium boundary layer. All of these previous studies mainly focused on the length and height effects of a wind tunnel on the flows with saltation,

* Corresponding author. Tel.: +86 10 62751185; fax: +86 10 62756526.
E-mail addresses: fengdajun@iee.pku.edu.cn (D.J. Feng), nijinren@iee.pku.edu.cn (J.R. Ni).

0169-555X/$ – see front matter © 2008 Elsevier B.V. All rights reserved.
doi:10.1016/j.geomorph.2008.11.006

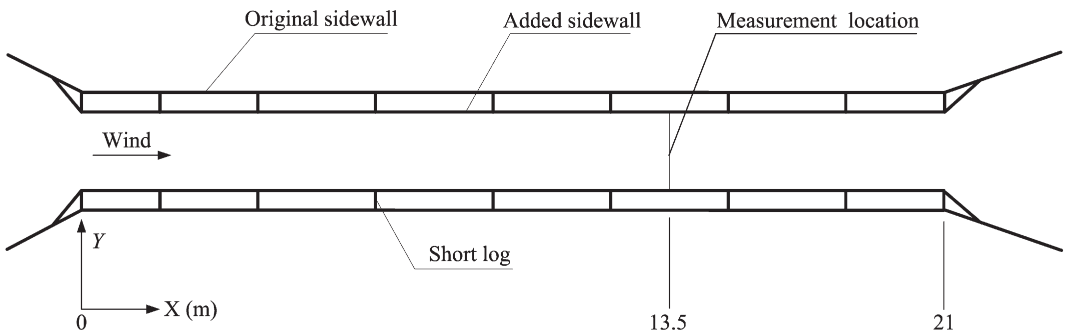

Fig. 1. Schematic diagram of the test section of the wind tunnel used for the experiments (Dimensions are in m).

while few investigations have been performed to study the tunnel sidewall effects.

The wind tunnel width is one of the major factors that determine if sidewall effects need to be considered. Rasmussen and Mikkelsen (1991) concluded that sidewalls would influence experimental results in a narrow wind tunnel 5 cm wide, as used by Kawamura (1951). Horikawa and Shen (1960) measured the wind velocity profiles across a test section of the wind tunnel with a width-to-height ratio of 0.78, and found that sidewall effects on the wind velocity profile could be ignored in a wide wind tunnel. Belly (1964) revealed that the ratio of the flow depth influenced by the sidewalls to the width is about 0.23 in a wind tunnel with a width-to-height ratio of 1.6. Williams (1964) and Gillette (1978) also measured the wind velocity profiles in cross sections of wind tunnels, but they did not discuss any tunnel sidewall effects on wind-blown sand transport. Therefore, these previous results are inconclusive and uncertainties still exist.

In this study, the influences of width on flow pattern and particle mass flux in wind tunnel simulations of aeolian transport were investigated experimentally. Both vertical profiles of wind velocity and sand mass flux were measured at different locations across the test section in a wind tunnel with experimentally variable widths. Section 2 briefly outlines the experimental arrangement and instrumentation. Section 3 presents the vertical profiles of wind velocity in the transverse section for five tunnel widths, and the relationship between the friction velocity and the saltation roughness length is compared with predictions. Section 4 shows the vertical distributions of sand mass flux at the quarter width location from the sidewall and along the central line of the wind tunnel, again for five widths. The discrepancy between sand mass fluxes at the two measurement locations is analyzed, followed by consideration of the relationship between the dimensionless sand transport rates and the dimensionless wind friction velocities. A dimensionless parameter is also proposed to estimate the sidewall effects on aeolian transport. Section 5 summarizes the main conclusions.

2. Experimental apparatus and procedure

The experiments were carried out in a straight-line blowing wind tunnel containing a bed of naturally-mixed sand. The 35 m long wind tunnel was located at the Shapotou Desert Research Station, Lanzhou Institute of Desert Research (Chinese Academy of Sciences). The wind tunnel was composed of centrifugal fan, flexible coupling, an expanding section, a settling section, a contraction section, a test section, and a diffuser section. Upon entering the tunnel, the flow was expanded, settled by honeycombs and a damping mesh, and then contracted, until entering the test section. The test section is 21 m long, 1.2 m high and 1.2 m wide. Finally, the flow was exited through a 3 m long diffuser. This wind tunnel system could ensure that a boundary layer was fully developed to a depth of about 20 cm. The floor of the test section consisted of seven panels, each of which was 3 m long and could be removed to meet specific experimental needs. These panels were used to add sidewalls in the experiments requiring wind tunnels narrower than the primary wind tunnel (Fig. 1). The ends of added sidewalls were connected to the primary sidewalls with plywood. Short logs were used for fixing the added sidewalls. The added sidewall was connected with the contraction section and diffuser section by the log inserts, which would affect the wind flow in the test section to some extent. This effect of the log inserts was inevitable in the present wind tunnel with varying width but was not expected to play a major role in determining wind flow since the test section was up to 21 m in length. Therefore, for different experiment runs, the tunnel width (B) between the two sidewalls was 120, 100, 80, 60, and 40 cm, respectively, and the tunnel height (H) was fixed at 120 cm.

Table 1
Summary of experimental conditions.

Run no.	Measurement items	Tunnel width (B) (cm)	Distance/width (Y/B)	Sampling duration (min)
1–2	Wind velocity (without saltation)	120	0.05/0.95	–
3–4	Wind velocity (without saltation)	120	0.15/0.85	–
5–6	Wind velocity (without saltation)	120	0.30/0.70	–
7	Wind velocity (without saltation)	120	0.50	–
8–9	Wind velocity	120	0.05/0.95	–
10–11	Wind velocity	120	0.15/0.85	–
12–13	Wind velocity	120	0.30/0.70	–
14	Wind velocity	120	0.50	–
15–16	Wind velocity	100	0.05/0.95	–
17–18	Wind velocity	100	0.15/0.85	–
19–20	Wind velocity	100	0.30/0.70	–
21	Wind velocity	100	0.50	–
22–23	Wind velocity	80	0.050.95	–
24–25	Wind velocity	80	0.15/0.85	–
26–27	Wind velocity	80	0.30/0.70	–
28	Wind velocity	80	0.50	–
29–30	Wind velocity	60	0.05/0.95	–
31–32	Wind velocity	60	0.15/0.85	–
33–34	Wind velocity	60	0.30/0.70	–
35	Wind velocity	60	0.50	–
36–37	Wind velocity	40	0.05/0.95	–
38–39	Wind velocity	40	0.15/0.85	–
40–41	Wind velocity	40	0.30/0.70	–
42	Wind velocity	40	0.50	–
43	Mass flux	120	0.50	3
44–45	Mass flux	120	0.25/0.75	3
46	Mass flux	100	0.50	2
47–48	Mass flux	100	0.25/0.75	2
49	Mass flux	80	0.50	1
50–51	Mass flux	80	0.25/0.75	1
52	Mass flux	60	0.50	1/2
53–54	Mass flux	60	0.25/0.75	1/2
55	Mass flux	40	0.50	1/3

Note that tunnel height is fixed (120 cm); Y is the measurement transverse distance from the left sidewall of wind tunnel.