Experimental investigation of sand velocity on barchans in windblown sand transport in the wind tunnel

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Summary Current theoretical and experimental studies of windblown sand movement mostly consider flat sand surface. However, sand dunes are basic forms of desert landscape, and the slope gradient has a great influence on the transportation of sand particles. In this paper sand velocities on the barchans slope are measured using laser technique of PDPA in the wind tunnel. The results are helpful to understand the motion regularities of sand particles on barchans.

Introduction

Extensive experiment and numerical simulation were carried out to study the distributions of both impact and lift-off particles in windblown sand movement on flat bed, which have significant influences on the particle trajectories and the transport flux of sand particles. For example, Mitha, Tran, Werner and Haff.etc [1] obtained relationship between lift-off velocity and impact velocity through experiment in 1986. In 2001, Zou et al. [2] investigate sand velocity and energy at different height by PDPA. Xie and Zheng [3] established a two-dimensional collision model to study lift-off velocities of sand particles in 2003. Kang et al. [4],[5] obtained some characteristics of sand velocity on flat bed through numerical and experimental methods in 2008. In this paper sand velocities on the barchans slope are measured using laser technique of PDPA in the wind tunnel and the distributions of both impact and lift-off particles on windward as well as leeward slope are obtained through analyzing experimental data.

Equipment and method

The experiment was carried out in a sand wind tunnel at the Key Laboratory of Mechanics on Disaster and Environment in Western China (Lanzhou University), the Ministry of Education of China. The wind tunnel is a blow-type non-circulating wind tunnel. The working section of wind tunnel is 20 m long. The cross-section of working section is 1.3 m wide and 1.45 m high. The free-stream wind velocity in the wind tunnel can be changed continuously from 1 to 40 m/s. Natural quartz sand in Tengger Desert is chosen for the sand samples. The layer of sand samples is about 12 m long, 1.3 m wide and 15-20 cm deep. The sand bed surface is leveled to the wind tunnel floor.
The movement of blowing grains in saltation is measured by a Phase Doppler Particle Analyzer (PDPA). The PDPA has many advantages. It is a non-intrusive measurement using an optical technique with a high accuracy, and can give objective statistical results for many particles. The free-stream wind velocity is measured by velocity profile analyzer. The sketch of the experimental set-up in the working section of wind tunnel is shown in Fig.1. There are 7 measurement points on the slope, which is shown in Fig.2. We use Particle Size Analyzer to obtain the distribution of sand particles size shown in Fig.3, which can be expressed as Lognormal function.

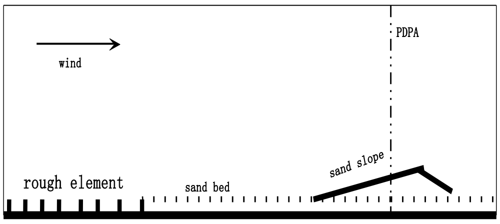

Fig.1 Sketch of the experimental set-up in the working section of wind tunnel

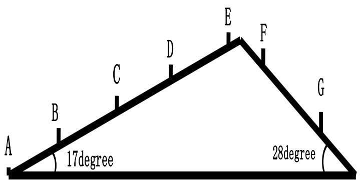

Fig.2 Sketch of measurement point

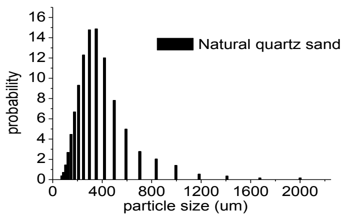

Fig.3 Sand particles size

Results and analysis

Velocity distribution of impact and lift-off particles on the slope

By fitting the experimental data, the probability distribution of impact and lift-off particles can be expressed as Lognormal function as follows:

$$P(u_i^*) = y^0 + \frac{a}{\sqrt{2\pi} w u_i^*} \exp[-\frac{(\ln u_i^* - \ln x_c)^2}{2w^2}]$$

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u_i^* is non-dimensional velocity of impact or lift-off particles, $u_i^* = u_i / \overline{U}_i$, u_i is velocity of impact or lift-off particles, $\overline{U}_i$ is the mean velocity of impact of lift-off particles. R^2 is coefficient of fitting curves. y^0, x_c, w, a are fitting constants. The fitting curves are shown in Fig.4 and Fig.5.

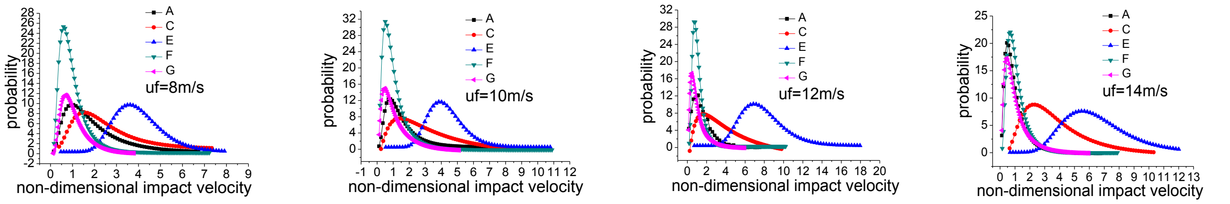

Fig.4 Fitting curves of non-dimensional impact velocity

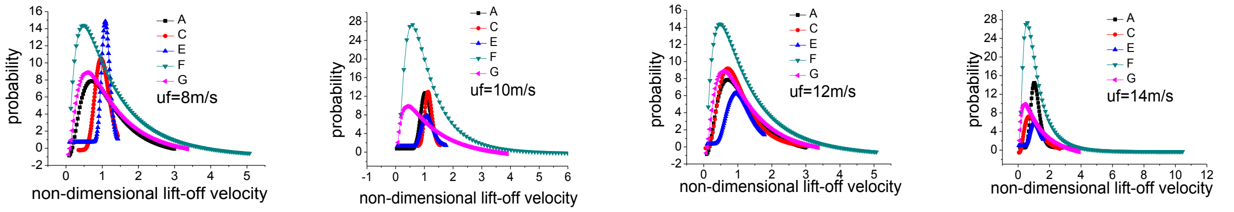

Fig.5 Fitting curves of non-dimensional lift-off velocity

Turbulence intensity of sand particles on the leeward slope

The turbulence intensity of particles is a reflection of particles velocity fluctuation. The turbulence intensity can be calculated as:

$$T_H = \frac{1}{u_m}\sqrt{\frac{1}{N}\sum_{i=1}^{N}(u_i - u_m)^2} \qquad T_V = \frac{1}{v_m}\sqrt{\frac{1}{N}\sum_{i=1}^{N}(v_i - v_m)^2}$$

where T_H and T_V are the horizontal and vertical particle turbulence intensity, respectively. u_m and v_m are the mean horizontal and vertical velocities of grains, respectively. u_i and v_i are the horizontal and vertical velocities of particle i, respectively. N is the number of the statistical particles. The turbulence intensity of particles on the bottom of leeward slope is shown in Fig.6.

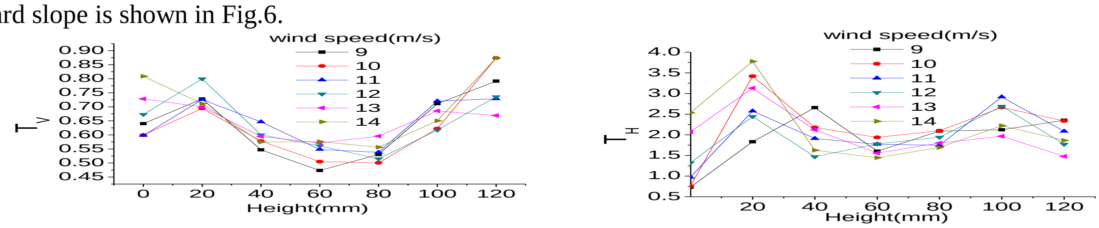

Fig.6 The turbulence intensity of particles on the bottom of leeward slope in vertical(left) and horizontal(right) direction

Conclusion

From Fig.4 and Fig.5, it can be seen that the resultant velocity of impact and lift-off particles probability distribution profiles are shown as Lognormal function which have a typical peak and are right-skewed below the middle of windward slope, and upward the middle of windward slope, the velocity probability profile would be slowly close to Normal distribution as it approaches the top of windward slope. The impact velocity are usually larger than lift-off velocity and the sand velocities of impact and lift-off particles on the leeward slope are smaller than that on the windward slope. From Fig.6 it can be seen that on the bottom of leeward slope, the particle intensity both in vertical and horizontal direction reach maximum at a height of 20mm and minimum at a height of 60mm. It also can be seen that the turbulence intensity of particles in both horizontal and vertical directions increase with wind speed on the leeward slope. And the particle intensity in horizontal direction is larger than that in vertical direction.

References

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