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Experimental investigation on trap stagnant effect and sand flux in aeolian sand transport

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Abstract

A new isokinetic vertical sand trap is designed in this work, and the new trap has an advantage that airflows in all sampling tubes at different height can simultaneously approach the isokinetic state. The stagnant effect and vertical sand mass flux are experimentally investigated in a wind tunnel. Compared with the traditional passive sand trap, the new design greatly reduces the stagnant effect, and has higher efficiency at different heights and wind speeds. The results obtained in this Letter also show the stagnant effect of the sand trap not only changes the total efficiency of the sand collection, but also the distribution of the vertical sand flux. The new isokinetic sand trap has good performance and can be applied to study the sand flux in aeolian sand transport.

Keywords: Aeolian sand transport; Sand trap; Sand mass flux

1. Introduction

Aeolian sand transport is an important sediment transport process in nature, and can cause some environmental problems (e.g. air pollution, soil erosion and desertification etc.). Bagnold [1] made the early attempts to study the sand transport in wind tunnel and field. Subsequently, a great number of experiments and numerical efforts have been made and reported by many researchers [2–12]. Measurements of vertical sand flux profile are crucial for the study of aeolian sand transport. Data from many wind tunnel investigations revealed that the vertical mass flux decreases rapidly with height, and can be expressed as a power law or exponential law [13]:

$$q(z)=\left(\frac{a}{z+c}\right)^{1/n} \tag{1}$$

where $q(z)$ is the mass flux at the height z, a, c and n are coefficients.

$$q(z)=q_0 e^{-z/b} \tag{2}$$

where q_0 are the mass flux at the bed surface ($z=0$), b is a constant length scale.

Sand traps are the main instruments to measure the sand transport, and can be divided into two groups: horizontal sand traps and vertical sand traps. Horizontal sand traps have often been used to measure the longitudinal distribution of sand mass flux. Owen [14] suggested that the mean saltation height is proportional to the mean saltation length. So the vertical mass flux distribution can also be obtained from the longitudinal distribution [15], but the relations between the vertical and longitudinal distributions are still undeveloped. Vertical sand traps are more popular because they are convenient and inexpensive ways to achieve the vertical mass flux distribution. As an obstacle in the flow, a vertical sand trap always distorts the flow and the particles' trajectories, and the trap efficiency deviates from unity. New configurations of the sand trap have been developed continuously for decades to improve the trap efficiencies. However, only a few of the numerous sand trap configurations have been calibrated.

The idealized sand trap is the isokinetic or active sand trap, which has a special pumping system to maintain the airflow

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velocity at the trap orifices equal to the velocity that would be achieved without trap disturbance [16,17]. Active traps do not distort the flow neither the particles' trajectories, so they have higher efficiency than traditional passive traps, and the added advantage of no discrimination for collecting smaller and larger particles [18]. But in practice, the absolute isokinetic state is unreachable.

In recent years, sand trap efficiency has been a matter of great concern for several researchers. Calibrations of the sand traps were reported in many references [10,17–22]. Nickling and McKenna Neuman [18] investigated a wedge-shaped sand trap in wind tunnel. They tested the trap efficiency by directly weighting the sediment entering the trap orifice with a sensitive electronic balance. Dong et al. [8] designed a WITSEG sampler and made an evaluation of overall sampling efficiency. The efficiency was defined as the ratio of the collected total flux by sampler to the true total flux calculated by weighting the sand sample on the wind tunnel floor before and after test. An average efficiency of 0.91 was obtained under wind speeds 8–22 m/s.

Rasmussen and Mikkelsen [20] measured the efficiency of three vertical sand traps including the Aberdeen, the Ames and the Aarhus trap, and compared them with an isokinetic sand trap. These three different traps show a tendency that, the trap efficiency is fairly high (>80%) at heights greater than 15 mm, but very low at the near bed region (50–70%). Goossens et al. [21] tested the efficiency of five single tube sand samplers. The samplers were calibrated against a commercial isokinetic sampler, registered as the Sartorius Membramfilter SM16711. The result showed the sampler efficiency is somewhat lower for fine sands or for high wind speed.

However, the isokinetic traps used by Rasmussen and Mikkelsen [20] and Goossens et al. [21] have some disadvantages. The trap used by Rasmussen was made from six brass tubes, and the air suction in each tube was adjusted by six valves individually; the complexity of the adjustment limited the number of sampler tubes that could be used. The Sartorius used by Goossens has a regulator button on the control panel, and the actual flow rate can be read at any time. However, it is designed mainly for the single point measurement.

In this Letter, we have designed a new kind of isokinetic sand trap. The vertical profiles of sand flux are measured, and the performances between the new sand trap and a traditional passive vertical sand trap are compared in wind tunnel. A non-dimensional parameter is suggested to indicate the level of stagnation effect. The data obtained are compared with earlier published reports.

2. Trap design

The new active sand trap is designed to permit measurements of the vertical flux profile of blown sand in a wind tunnel. Unlike the active single tube traps, the active vertical trap has a tube array, and the air velocity in each tube under isokinetic state is different. Therefore, the key for design is to make the air velocities at each tube inlet simultaneously match the upwind velocities without the trap existence.

The construction scheme and photograph of the new trap are shown in Figs. 1 and 2. The trap is composed of the inner tube array and the outer shell. The tube array is a stack of 20 rectangular stainless steel tubes, just like a passive vertical sand trap. The orifice of each individual tube is $20 \times 10 \times 0.6$ mm (width × height × thickness), and the tube length is 250 mm. The walls on both opposing sides of the tube are replaced with screens. The tube array is embedded in the outer shell. An overall vent hole of 60 mm diameter is on the top of the shell,

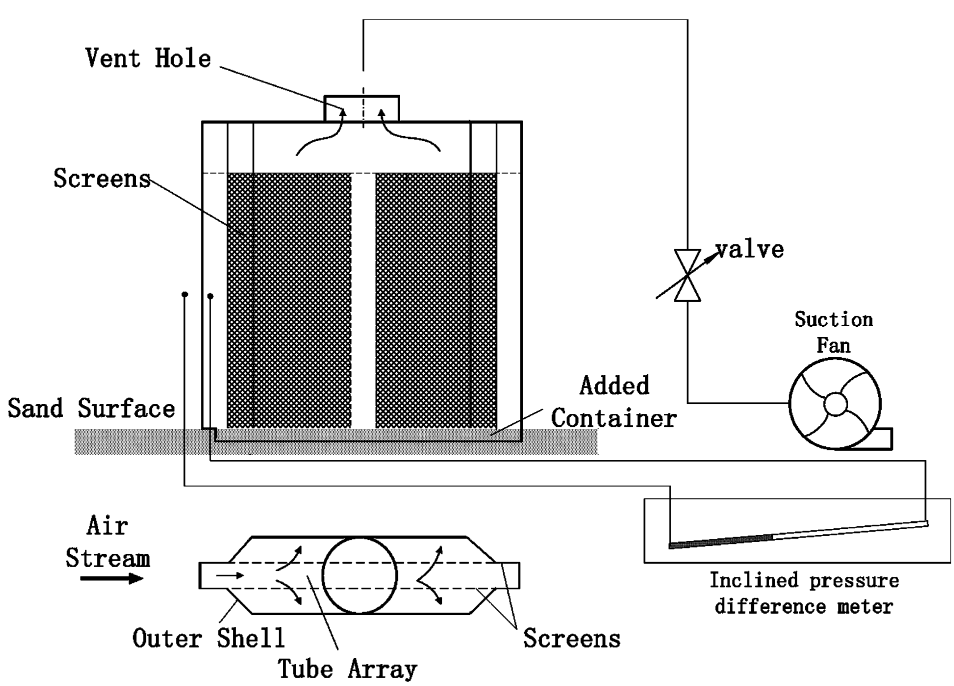

Fig. 1. Construction scheme of the active vertical sand trap.