Postprint of Wind Tunnel Simulation-Based Experimental Study on the Windbreak Effect of Slot-Type Sand Barriers

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Abstract

To prevent severe scouring at the bottom of vertical sand barriers under direct pressure, which forms concave surfaces within the barrier grids and leads to tilting of the barrier edges, changes in grid area, and reduced protection efficiency, a new barrier shape called the "trough-shaped sand barrier" is proposed. This design enhances wind erosion resistance and ground conformity by increasing self-weight through sand covering. Based on wind tunnel experiments conducted at three wind speeds (6 $m \cdot s^{-1}$, 9 $m \cdot s^{-1}$, and 12 $m \cdot s^{-1}$), wind speed data were obtained for trough-shaped sand barriers with various heights and angles (equal height front and back, lower front and higher back, and angular types). The wind protection effects were thoroughly investigated by calculating and analyzing indicators such as flow field structure, wind speed profiles, and acceleration rates. The results indicate that the deployment of trough-shaped sand barriers effectively reduces wind speed, with the overall wind protection effect characterized by five distinct functional zones that significantly influence near-surface airflow movement. Under the same angle conditions, the airflow acceleration rate shows an upward trend as the barrier height increases; however, the barrier angle should not be set too large to avoid weakening the wind protection effect. After the deployment of the barriers, surface roughness decreases as the incoming wind speed increases, showing a negative correlation, while the friction velocity increases linearly with wind speed, exhibiting a significant positive correlation. The results of this study aim to establish an optimized design theory and supporting technical system for sand control engineering, providing a scientific basis for engineering practice.

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Full Text

Wind Tunnel Simulation of the Wind-Shielding Effects of Slot-Type Sand Barriers

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Abstract

To prevent severe scouring at the base of vertical upright sand fences—which often leads to the formation of concave surfaces within grid cells, tilting of the fence structure, changes in the grid area, and a subsequent reduction in protective efficiency—this study proposes a new configuration called the "trough-shaped sand barrier." This design enhances wind erosion resistance and ground fit by utilizing sand cover to increase its self-weight. Based on wind tunnel experiments conducted at three wind speeds (6 $m \cdot s^{-1}$, 9 $m \cdot s^{-1}$, and 12 $m \cdot s^{-1}$), wind speed data were collected for trough-shaped sand barriers with various heights and configurations (including uniform height, front-low/rear-high, and angled types). The windbreak effects were investigated in depth by analyzing the flow field structure, wind speed profiles, and acceleration rates.

The results indicate that the deployment of trough-shaped sand barriers effectively reduces wind speed, with the overall windbreak effect characterized by five distinct functional zones that significantly influence near-surface airflow. Under identical angle conditions, the airflow acceleration rate shows an upward trend as the barrier height increases; however, the barrier angle should not be excessively large to avoid diminishing windbreak efficiency. Following installation, surface roughness decreases as the incoming wind speed increases (negative correlation), while the friction velocity increases linearly with wind speed (significant positive correlation). These findings contribute to the theoretical optimization of sand control engineering and provide a scientific basis for engineering practice.

Keywords: Trough-shaped sand barriers; wind tunnel testing; windbreak effect; flow field structure; roughness

Figure 1

Figure 1: Figure 1

Figure 3

Figure 2: Figure 3

1. Introduction

Wind erosion and sand movement pose significant threats to infrastructure and ecological stability in arid and semi-arid regions. Among various sand control measures, mechanical sand barriers are widely utilized due to their immediate effectiveness in altering the near-surface wind field and reducing sand transport. Mechanical sand barriers create physical obstacles by laying materials such as straw, clay, branches, gravel, or mesh on the sandy surface. These barriers stabilize the migration of surface sand, providing a stable environmental foundation for subsequent plant growth [**?**].

Traditional sand barriers often suffer from short lifespans and are susceptible to decay. Furthermore, severe scouring at the bottom of the windward side often forms concave surfaces, leading to structural tilting and sand leakage. To address these issues, this study investigates trough-shaped sand barriers. These structures function by increasing surface roughness, reducing near-surface wind speeds, and inhibiting the wind erosion of fine surface particles [**?**].

2. Materials and Methods

2.1 Experimental Design The experiments were conducted in the OFDY-1.2 mobile open-circuit wind tunnel at Inner Mongolia Agricultural University. The wind tunnel has a total length of 11.8 m, with a test section measuring 7.2 m in length and cross-sectional dimensions of 1.0 m (width) $\times$ 1.2 m (height). Wind speed is continuously adjustable from 0 to 18 $\mathrm{m \cdot s^{-1}}$.

2.2 Model Design and Layout The trough-shaped sand barriers were modeled at a 1:1 scale to ensure geometric and dynamic similarity [**?**]. A mesh material with a porosity of 40% was applied over a bamboo frame

. To simulate sand burial, gaps were filled with 2 cm thick foam blocks. Six configurations were tested: uniform height, front-low/rear-high, and various angled designs .

2.3 Measurement Parameters Wind speed was measured using a TSI9565-P anemometer at heights (z) of 0.5H, 1H, 1.5H, 2H, 3H, and 4H (where H = 10 cm). The primary metrics include:

1. Acceleration Rate (a_{xpq}):

$$a_{xpq} = \frac{V_{xpq}}{V_{0pq}}$$

where V_{xpq} is the wind speed at a specific point behind the barrier and V_{0pq} is the reference wind speed.

2. Aerodynamic Roughness (z_0) and Friction Velocity (u_*): Under neutral stability, the wind profile follows the logarithmic law [?]:

$$u(z) = \frac{u_*}{\kappa} \ln\left(\frac{z}{z_0}\right)$$

where κ is the von Kármán constant (0.4). Using the least squares method ($u_z = a + b\ln(z)$), we calculate:

$$z_0 = \exp(-a/b)$$

$$u_* = \kappa b$$

3. Results and Analysis

3.1 Wind Speed Flow Field Characteristics The introduction of trough-shaped sand barriers significantly alters the flow field [FIGURE:5]. As airflow approaches the barrier, a deceleration zone forms upstream. Upon passing over the trough, the flow undergoes separation and reattachment, creating a complex vortex system.

In uniform-height configurations (Barriers A and B), distinct low-velocity zones are formed. As height and base width increase, the affected area widens. In front-low/rear-high configurations (Barriers C and D), the low-velocity zone on the leeward side becomes more compressed and shifts forward as height increases. In angled configurations (Barriers E and F), turbulence is generated within $0H$ to $8H$ behind the barrier as airflow is uplifted over the structure.

3.2 Wind Speed Profiles The wind speed profiles demonstrate that the barriers interrupt continuous flow, dissipating kinetic energy. While bare surfaces follow a standard logarithmic distribution, the presence of barriers increases the vertical gradient of the airflow. As the height of the sand barrier increases, the wind speed reduction becomes more pronounced, particularly in the windward deceleration zone.

[FIGURE:2]

3.3 Roughness and Friction Velocity The experimental data reveals that the surface roughness length z_0 is significantly enhanced by the barriers, effectively reducing near-surface wind speeds. However, z_0 shows a negative correlation with incoming wind speed, while the friction velocity u_* exhibits a significant positive linear correlation with wind speed.

Figure 4

Figure 3: Figure 4

Figure 7

Figure 4: Figure 7

4. Conclusion

Trough-shaped sand barriers provide an effective alternative to traditional vertical fences by improving ground conformity and reducing basal scour. The front-low/rear-high configuration demonstrated superior performance in promoting stable sand deposition. These results provide a theoretical basis for optimizing the design of mechanical sand fixation systems in arid regions.

Figures

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