Effect of the W-beam central guardrails on wind-blown sand deposition on desert expressways in sandy regions Postprint

Authors: WANG Cui, LI Shengyu, LEI Jiaqiang, LI Zhinong, CHEN Jie, LI Shengyu

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Abstract

Many desert expressways are affected by the deposition of the wind-blown sand, which might block the movement of vehicles or cause accidents. W-beam central guardrails, which are used to improve the safety of desert expressways, are thought to influence the deposition of the wind-blown sand, but this has yet not to be studied adequately. To address this issue, we conducted a wind tunnel test to simulate and explore how the W-beam central guardrails affect the airflow, the wind-blown sand flux and the deposition of the wind-blown sand on desert expressways in sandy regions. The subgrade model is 3.5 cm high and 80.0 cm wide, with a bank slope ratio of 1:3. The W-beam central guardrails model is 3.7 cm high, which included a 1.4-cm-high W-beam and a 2.3-cm-high stand column. The wind velocity was measured by using pitot-static tubes placed at nine different heights (1, 2, 3, 5, 7, 10, 15, 30 and 50 cm) above the floor of the chamber. The vertical distribution of the wind-blown sand flux in the wind tunnel was measured by using the sand sampler, which was sectioned into 20 intervals. In addition, we measured the wind-blown sand flux in the field at K50 of the Bachu-Shache desert expressway in the Taklimakan Desert on 11 May 2016, by using a customized 78-cm-high gradient sand sampler for the sand flux structure test. Obstruction by the subgrade leads to the formation of two weak wind zones located at the foot of the windward slope and at the leeward slope of the subgrade, and the wind velocity on the leeward side weakens significantly. The W-beam central guardrails decrease the leeward wind velocity, whereas the velocity increases through the bottom gaps and over the top of the W-beam central guardrails. The vertical distribution of the wind-blown sand flux measured by wind tunnel follows neither a power-law nor an exponential function when affected by either the subgrade or the W-beam central guardrails. At 0.0H and 0.5H (where H=3.5 cm, which is the height of the subgrade), the sand transport is less at the 3 cm height from the subgrade surface than at the

1 and 5 cm heights as a result of obstruction by the W-beam central guardrails, and the maximum sand transportation occurs at the 5 cm height affected by the subgrade surface. The average saltation height in the presence of the W-beam central guardrails is greater than the subgrade height. The field test shows that the sand deposits on the overtaking lane leeward of the W-beam central guardrails and that the thickness of the deposited sand is determined by the difference in the sand mass transported between the inlet and outlet points, which is consistent with the position of the minimum wind velocity in the wind tunnel test. The results of this study could help us to understand the hazards of the wind-blown sand onto subgrade with the W-beam central guardrails.

Full Text

Preamble

Effect of W-Beam Central Guardrails on Wind-Blown Sand Deposition on Desert Expressways in Sandy Regions

WANG Cui[1],[2],[3], LI Shengyu[1]*, LEI Jiaqiang[1], LI Zhinong[3], CHEN Jie[3]

[1] Xinjiang Institute of Ecology and Geography, Chinese Academy of Sciences, Urumqi 830011, China
[2] University of Chinese Academy of Sciences, Beijing 100049, China
[3] Research Center of Desert Highway Engineering, Xinjiang Institute of Ecology and Geography, Chinese Academy of Sciences, Urumqi 830011, China

Abstract: Many desert expressways are affected by wind-blown sand deposition, which can obstruct vehicle movement or cause accidents. W-beam central guardrails, installed to improve safety on desert expressways, are thought to influence wind-blown sand deposition, though this effect has not been adequately studied. To address this knowledge gap, we conducted wind tunnel tests to simulate and investigate how W-beam central guardrails affect airflow, sand flux, and deposition patterns on desert expressways in sandy regions. The subgrade model measured 3.5 cm in height and 80.0 cm in width, with a bank slope ratio of 1:3. The W-beam central guardrails model stood 3.7 cm tall, comprising a 1.4-cm-high W-beam and a 2.3-cm-high support column. Wind velocity was measured using pitot-static tubes positioned at nine heights (1, 2, 3, 5, 7, 10, 15, 30, and 50 cm) above the chamber floor. The vertical distribution of wind-blown sand flux was measured using a sand sampler divided into 20 intervals. Additionally, we measured sand flux in the field at K50 of the Bachu-Shache Desert Expressway in the Taklimakan Desert on May 11, 2016, using a customized 78-cm-high gradient sand sampler. Subgrade obstruction creates two weak wind zones at the foot of the windward slope and on the leeward slope, with wind velocity decreasing significantly on the leeward side. The W-beam central guardrails further reduce leeward wind velocity, while velocity increases through bottom gaps and over the top of the guardrails. The vertical distribution of sand flux measured in the wind tunnel follows neither a power-law nor exponential function when influenced by either the subgrade or guardrails. At 0.0H and 0.5H (where H = 3.5 cm, the subgrade height), sand transport at 3 cm above the subgrade surface is less than at 1 and 5 cm heights due to guardrail obstruction, with maximum sand transport occurring at 5 cm above the subgrade surface. The average saltation height with guardrails present exceeds the subgrade height. Field tests show that sand deposits on the overtaking lane leeward of the guardrails, with deposit thickness determined by the difference in sand mass transported between inlet and outlet points, consistent with the location of minimum wind velocity observed in wind tunnel tests. These results enhance understanding of wind-blown sand hazards on subgrades with W-beam central guardrails.

Keywords: wind velocity field; wind-blown sand flux; W-beam central guardrails; sand deposition; desert expressway; wind tunnel test; Taklimakan Desert

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Corresponding author: LI Shengyu (E-mail: oasis@ms.xjb.ac.cn)

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1 Introduction

W-beam central guardrails are commonly installed on desert expressways to enhance vehicle safety (Jason et al., 2005). In recent years, wind-blown sand deposition on subgrade surfaces with W-beam central guardrails has become a concern (Li et al., 2016), as sand erosion and deposition represent primary sources of sand-related damage to desert expressways (Lei et al., 2008; Cheng et al., 2015). Subgrade height and slope affect airflow, which correlates negatively with wind velocity, and eddy airflow forms leeward of the subgrade (Yang et al., 2010). Settlement of sand particles at the foot of both leeward and windward slopes results in roadbed sand deposition (Zhang et al., 2010; Yang et al., 2011).

The Taklimakan Desert, China’ s largest mobile desert, is characterized by an arid climate with minimal precipitation. The Taklimakan Desert Highway, constructed in 1995, features a comprehensive sand-control system of straw checkerboard barriers and fences that reduce wind velocity and sand deposition, protecting the highway from burial by wind-blown sand (Cheng et al., 2015). Huang et al. (2013) and Xu et al. (2018) simulated turbulent flow and sand particle motion over straw checkerboard barriers. Wind fences, used to protect areas from high winds and sand damage, have been studied to determine optimum protection distance, wind reduction efficiency, and optimal porosity (Dong et al., 2006, 2007; Li and Douglas, 2015; Zhan et al., 2017). Shelterbelt systems in the Taklimakan Desert have also been investigated, demonstrating that shelterbelts can control wind-blown sand damage while providing ecological benefits (Lei et al., 2008).

Significant research has examined how fences affect the vertical distribution of wind-blown sand flux, how fence porosity influences sediment deposition, and why sand accumulates upwind of low-porosity fences but downwind of high-porosity fences (Dong et al., 2004; Cornelis and Gabriels, 2005). Large-diameter sand particles deposit on the windward side of fences, while suspended particles pass through, and leeward deposits remain stable due to eddy airflow direction and intensity (Zheng et al., 2011). Mean sand velocity decreases dramatically and particle concentration declines leeward of fences, with vertical sand distribution following an exponential function (Zhang et al., 2010).

As road transportation develops in desert regions, demand for desert expressway construction increases (Zheng et al., 2011). High-speed expressways differ substantially from low-speed roads in subgrade structure and safety requirements. Higher subgrades, central guardrails, and anti-glare nets on desert expressways tend to increase sand deposition on subgrade surfaces (Yang et al., 2010). W-beam central guardrails have created new types of sand damage, yet their interaction with airflow and wind-blown sand remains unclear. This study employs wind tunnel and field tests to investigate airflow characteristics associated with wind-blown sand around W-beam central guardrails. The results enhance understanding of wind-blown sand hazards caused by subgrades with W-beam central guardrails.

2.1 Wind Tunnel Test of Wind Velocity

A scaled simulation experiment was conducted in a wind tunnel at the Desert Research Station of Mosuowan, Xinjiang Institute of Ecology and Geography, Chinese Academy of Sciences. The blower-type non-circulating wind tunnel measured 16.2 m in total length, including an 8-m-long test section that was 1.3 m wide and 1.0 m high. Inlet wind velocity ranged from 1 to 20 m/s, with a boundary layer thickness of approximately 15 cm at an inlet velocity of 12 m/s (Zheng et al., 2012).

Figure 1 [Figure 1: see original paper] illustrates the experimental setup. The prototype W-beam central guardrails on the Bachu-Shache Desert Expressway in the Taklimakan Desert consisted of a 28-cm-high W-beam and 46-cm-high support columns. The wind tunnel model represented a 1:20 scaled-down version of this expressway design, comprising two components: the subgrade and the W-beam central guardrails. The subgrade model measured 3.5 cm in height and 80.0 cm in width, with a bank slope ratio of 1:3. The guardrails model stood 3.7 cm tall, including a 1.4-cm-high W-beam and a 2.3-cm-high support column. Figure 2a [Figure 2: see original paper] shows field photographs of the guardrails, while Figure 2b shows the scaled model used in wind tunnel tests.

Wind velocity was measured for two configurations: (1) subgrade without guardrails and (2) subgrade with guardrails. Measurements were obtained using pitot-static tubes positioned at nine heights (1, 2, 3, 5, 7, 10, 15, 30, and 50 cm) above the chamber floor. The tubes connected to calibrated pressure transducers via thin plastic tubing. Test points upstream of the guardrails were located at -20.0H, -15.0H, -10.0H, -8.5H, -7.0H, -3.5H, and -1.0H (where H = 3.5 cm, the subgrade height). Downstream test points were positioned at 1.0H, 3.5H, 7.0H, 8.5H, 10.0H, 15.0H, 20.0H, 25.0H, and 30.0H, with an additional point at 0.0H at the guardrails center. Inlet wind velocity was determined by hot-wire anemometry at 50 cm height, with test velocities of 8, 10, and 12 m/s. Temperature, relative humidity, and atmospheric pressure were measured using a hygrothermograph positioned just outside the wind tunnel.

The physical airflow in wind tunnel tests must follow correct simulation principles. Full-scale flow processes can be simulated in the laboratory by matching non-dimensional coefficients of motion equations between scaled experiments and field conditions (White, 1996). Three parameters require consideration: the Rossby number, bulk Richardson number, and Reynolds number (Re = vL/ , where is fluid density (cm^3), v is velocity (m/s), L is characteristic length (m), and is viscosity coefficient (Pa·s)). Rossby number effects can be ignored when laboratory tests are restricted to the lowest 10.0%-15.0% of boundary layer height. When tests are conducted in the lowest 7.2% of boundary layer height, the longitudinal velocity spectrum in the inertial subrange is accurately modeled. The bulk Richardson number is zero for neutral-stability atmospheric flow, easily simulated in the laboratory through isothermal conditions. A Reynolds number exceeding 1.0$×10^{4}$ is scale-independent. In this study, the minimum wind tunnel test velocity was 8 m/s over a subgrade width of 80 cm, yielding a Reynolds number of 46.0$×10$^{\{4\}, whichisthereforescale-independent.Consequently, airflowoverthescalemodelwasdynamicallysimilartofull-scalefi}$ and a blocking degree of 3.9%.

2.2 Structure of Wind-Blown Sand Flux and Sand Deposition Patterns

Wind-blown sand flux structure was measured in the wind tunnel using sand with a median particle diameter of 138.8 m, as determined by a Malvern particle-size analyzer (Mastersizer 2000, Malvern Instruments Ltd., UK). A 20-cm-deep sand layer (approximately 1 m × 1 m) was placed on the wind tunnel floor about 2.0 m downwind from the test section entrance. A 20-cm-tall sand sampler, sectioned into 20 intervals (each 1 cm × 1 cm), measured vertical sand particle distribution and flux. The sampler design and operating principles followed Dong et al. (2003). The sampler was positioned at -20.0H, -10.0H, -8.5H, -7.0H, 0.0H, 7.0H, 8.5H, 10.0H, and 20.0H to measure subgrade properties, and at -7.0H, -0.5H, 0.0H, 0.5H, and 7.0H to assess guardrail effects. Collected sand mass was measured using an electronic balance. Experimental wind velocity was

8 m/s, with each test lasting 10 minutes.

Field testing of wind-blown sand flux was conducted at K50 of the Bachu-Shache Desert Expressway on May 11, 2016. This 28-m-wide expressway featured W-beam central guardrails. Sand flux was measured using a customized gradient sand sampler designed by Wang et al. (2016). The sampler contained 14 gradients (at heights of 2.0, 5.0, 7.5, 9.0, 13.0, 20.0, 25.0, 30.0, 37.0, 40.0, 50.0, 60.0, 70.0, and 78.0 cm) with a collector cross-section of 1.7 cm × 1.7 cm. Ten-minute measurements were taken on the sand bed, windward shoulder, and leeward shoulder to characterize field sand transport. Deposit thickness and area were measured using a flexible ruler following sandstorm events.

2.3.1 Reduction Rate of Wind Velocity

The wind velocity field serves as a comprehensive index of airflow movement. Wind velocity at a given height and distance above the subgrade can be expressed through the horizontal wind velocity reduction rate $R_c(x,z)$ (Wang et al., 2017):

$$R_c(x,z) = \frac{u_0(x,z) - u(x,z)}{u_0(x,z)} \times 100\% \tag{1}$$

where x is horizontal distance from the guardrails (H), z is height above the surface (cm), $u(x,z)$ is wind velocity above a surface with subgrade or at the measurement point (m/s), and $u_0(x,z)$ is inlet wind velocity (m/s). Here, $R_c(x,z) < 0$ indicates wind velocity exceeds inlet velocity, while $R_c(x,z) > 0$ indicates wind velocity is lower than inlet velocity.

2.3.2 Energy Loss Calculation

Airflow energy loss (ΔE) per unit volume can be expressed by Equation 2 (Ni and Li, 2001):

$$\Delta E = \frac{1}{2}\rho[u_0(x,z)^2 - u(x,z)^2] \tag{2}$$

where ΔE is airflow energy loss (J/m^3), ρ is air density (kg/m^3), $u_0(x,z)$ is inlet wind velocity (m/s), and $u(x,z)$ is wind velocity at the measurement point (m/s). Larger ΔE corresponds to reduced wind power, while $\Delta E < 0$ indicates increasing wind power.

2.3.3 Calculation of Sand Deposit Thickness

For desert expressways, the windward road shoulder acts as an inlet and the leeward shoulder as an outlet. The difference in wind-blown sand transport mass between windward and leeward sides determines the mass deposited on the subgrade surface. Assuming a deposition area 1.0 m wide, deposition thickness can be calculated by:

$$d = \frac{(Q_1 - Q_2) \times t}{10000 \times \rho} \tag{3}$$

where d is sand deposition thickness (cm), Q_1 is sand mass entering from the windward shoulder (g/(h·m)), Q_2 is sand mass exiting from the leeward shoulder (g/(h·m)), ρ is bulk density of sand particles (g/cm^3), and t is wind-blown sand accumulation duration (h).

2.3.4 Statistical Analysis

Origin Pro 9.0 was used for linear regression analysis and result plotting. Surfer 12.0 generated wind velocity field diagrams, and AutoCAD 2007 produced experimental setup schematic diagrams.

3.1 Wind Velocity Field

Figure 3 [Figure 3: see original paper] presents horizontal iso-velocity fields for subgrades with and without W-beam guardrails, measured under free-stream velocities of 8, 10, and 12 m/s. For subgrades without guardrails, horizontal wind velocity changes can be divided into five regions (Fig. 3a). Region I, located in front of the subgrade, exhibits decreasing horizontal wind velocity. A slight reduction occurs from -20.0H to -15.0H, where reduction coefficients remain below 9.0%. As distance from the subgrade surface decreases, horizontal wind velocity at 1 cm height declines further, with reduction coefficients of 28.0%-31% between -12.0H and -11.0H.

Region II shows increasing horizontal wind velocity as airflow compresses along the windward slope, increasing velocity by approximately 3.0%. Maximum velocity occurs on the windward shoulder. Airflow diffuses smoothly over the subgrade surface, maintaining stable horizontal wind velocity. Region III represents the zone of stable horizontal wind velocity over the subgrade surface, with reduction coefficients of 0.2%-0.6% at heights above 15 cm and 10.6%-18.0% at heights below 15 cm. The near-surface velocity decrease results from surface drag forces.

Region IV, downwind of the subgrade, exhibits decreasing horizontal wind velocity where airflow separation creates a low-velocity zone from 10.0H to 11.5H. Horizontal wind velocity reaches zero at the foot of the leeward slope, with reduction coefficients decreasing with height above the subgrade surface. Region V shows wind velocity recovery, with velocity increasing downwind of flow reattachment points and horizontal wind velocity recovering with increasing distance from the subgrade surface. The subgrade influences airflow up to 20.0H, beyond which reduction coefficients fall below 10.0% and airflow gradually returns to inlet velocity.

Figures 3b–d illustrate horizontal iso-velocity contours for subgrades with W-beam central guardrails at inlet velocities of 12, 10, and 8 m/s. Under combined subgrade and guardrail obstruction, wind velocity decreases from -3.5H to 30.0H, with reduction coefficients reaching 47.0% at 3.5 cm height above the subgrade at 0.0H. Reduction coefficients measure 27.0% at -3.5H and 18.0% at -0.5H at 1.5 cm height. The reduction coefficient increases to 47.0% at 3.5 cm height in front of the guardrails, while horizontal wind velocity increases by 1.0% relative to inlet velocity at 6.5 cm above the guardrails. At 0.5H behind the guardrails, the reduction coefficient is 37.0% at 1.5 cm height above the subgrade surface (Fig. 3b).

Minimum horizontal wind velocity on the subgrade surface occurs between 3.5H and 3.7H, decelerating to 0.93, 1.16, and 1.41 m/s at inlet velocities of 8, 10, and 12 m/s, respectively, with reduction coefficients reaching 60.0% at 1.5 cm height above the subgrade surface (Figs. 3b–d). At the 30.0H test point, horizontal wind velocity recovers to 72.0%–80.0% of inlet velocity. As inlet wind velocity increases, the horizontal wind velocity recovery distance decreases.

3.2 Changes in Airflow Energy Loss

Under subgrade influence, airflow energy loss ranges from -16.90 to 60.45 J/m^3 (Fig. 4 [Figure 4: see original paper]). Airflow energy increase concentrates at 5 cm height above the expressway shoulder, where wind erosion occurs readily due to enhanced airflow energy. Under combined subgrade and guardrail influence, energy loss varies from -2.90 to 90.40 J/m^3, with airflow energy increasing above and below the guardrails. At 0.5H behind the guardrails, energy loss reaches 90.40 J/m^3, making this location susceptible to sand particle deposition. Overall, energy loss is greater for subgrades with guardrails than without (Fig. 4), with reduced airflow power causing wind-blown sand particles to settle in this region.

3.3 Changes in Vertical Distribution of Wind-Blown Sand Flux

In the presence of subgrade and guardrails, wind-blown sand flux vertical distribution does not decay exponentially with height, and maximum sand transport concentrates at higher elevations above the subgrade (Fig. 5 [Figure 5: see original paper]). The subgrade alone (without guardrails) concentrates maximum sand transport between 3 and 5 cm above the subgrade surface, decreasing at 0-1 cm heights (Fig. 5a). These transport characteristics result from the underlying solid subgrade surface, where saltating particles lose minimal momentum during collisions and the majority rebound to heights exceeding those over soft sand beds. At the leeward slope toe, sand particles are lifted by the subgrade, with maximum transport occurring at 5 cm height. At the front and leeward sides of the subgrade, sand transport decreases with increasing height, consistent with flat sand bed flux structure (Fig. 5a).

Figure 5b demonstrates that guardrails alter wind-blown sand flux structure over the expressway subgrade. Under guardrail influence, sand transport decreases from 65.0% (-7.0H) to 30.0% (0.5H) at 1 cm above the subgrade surface. Some particles are lifted by up-flow, increasing transport with height. However, despite this lifting, maximum sand transport remains concentrated at 1 cm height due to bleed flow. At test points 0.0H and 0.5H, sand transport at 3 cm height is less than at 1 and 5 cm heights, respectively, attributable to guardrail obstruction.

The average saltation height characterizes wind-blown sand flux profile, defined as the height corresponding to the 50% cumulative percentile (Wu, 1987). Figure 6 [Figure 6: see original paper] shows average saltation height for subgrades with and without guardrails. Without guardrails, average saltation height ranges from 0.61-0.89 cm in front of the subgrade and windward shoulder, increasing to 2.72-3.96 cm on the subgrade surface at 0.0-7.0H, and reaching 4.31-5.17 cm leeward of the subgrade. Saltation flux over the subgrade surface is maintained by successive saltating particles that extract energy from the wind and rebound elastically from the subgrade with additional energy, rising to greater heights. With guardrails, average saltation height exceeds that without guardrails, varying from 3.94 to 5.06 cm, indicating more particles moving in higher layers near the guardrails. This results primarily from uplift flow above the guardrails that pushes saltation particles to greater heights.

3.4 Sand Particle Deposition Thickness

Field tests show that wind-blown sand flux follows a power-law function with correlation coefficients between 0.81 and 0.95 (Table 1). Sand flux at 1-20, 20-40, and 40-80 cm heights accounts for 64.50%-82.31%, 9.87%-17.26%, and 7.82%-18.24% of total flux in the 0-80 cm layer, respectively (Table 1).

Table 1 Parameters of wind-blown sand flux structure from field tests

Underlying surface	Power-law fit	Sand transport (kg/(h · m))	Percentage of sand flux to total flux in 0–80 cm layer (%)
			0–20 cm
Mobile sand bed	$y = 169.36x^{-1}$· 015	73.1	64.50
Windward shoulder	$y = 615.6x^{-1}$· 335	17.1	82.31
Leeward shoulder	$y = 253.73x^{-0}$· 92	15.3	78.45

To estimate sand transport in the 0–80 cm layer, we integrated the power-law function of sand flux structure. Sand transport measured 73.1 kg/(h · m) over the sand bed and 17.1 kg/(h · m) at the windward shoulder. Leeward shoulder sand flux was 15.3 kg/(h · m). Sand transport over the sand bed exceeded that over the subgrade surface because the sand bed provides a greater sand source. Some particles deposit under subgrade slope influence, and without new sand supply, concentration remains lower than on the sand bed.

Using the May 11, 2016 sandstorm at K50 of the Bachu-Shache Desert Expressway as an example (Fig. 7 [Figure 7: see original paper]), inlet and outlet sand masses were 17.1 and 15.3 kg/(h · m), respectively, with particle bulk density of approximately 1.65 g/cm^3. The 10-hour sandstorm produced a modeled sand depth of about 1.1 cm, calculated using Equation 3.

Field investigation revealed that this sandstorm deposited sand in a 0.2–0.3-cm-thick strip, with deposition volume depending on both available sand quantity and wind power. Sand deposition occurs primarily on the leeward side of guardrails in the overtaking lane. In field tests, the overtaking lane was located 65–440 cm from the guardrails. Expressway sand deposition correlates with minimum wind velocity and airflow patterns observed in wind tunnel tests.

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4 Discussion

On desert expressways with W-beam central guardrails, airflow is affected by combined subgrade and guardrail action. Around guardrails on the subgrade surface, approaching flow compresses and separates into two components: bleed flow and lift flow. Bleed flow passes through gaps at the guardrail base and becomes slightly compressed, increasing velocity. Lift flow passes over the guardrail top, also increasing velocity. Lift flow separates at the guardrail' s downwind edge, creating reversed flow leeward of the guardrails. This reversed negative flow meets positive bleed flow from guardrail base gaps, causing the reversed airflow to dissipate and positive wind velocity to decrease. Airflow fields behind porous fences are complicated by both bleed flow through fence gaps and displaced airflow over the fence (Dong et al., 2007). The eddy zone disappears when fence porosity exceeds 40% (Lee and Kim, 1999).

Wind velocity variations represent airflow energy, with higher velocities transporting more sand. When sufficient sand is available, sand discharge is proportional to wind velocity cubed (Bagnold, 1941). Subgrade and guardrails exert drag on the wind field, causing net momentum loss in incompressible airflow and creating a shelter effect. The additional drag from guardrails increases friction velocity and roughness elements. As airflow loses energy, lower-momentum aeolian sand becomes disequilibrated, causing particles to settle in low-velocity zones (Thomas et al., 2014).

Wind-blown sand flux is not positively correlated with height, and both maximum sand mass density and particle saltation height increase, similar to Gobi region results reported by Zhang et al. (2015). Sand flux is affected by inlet wind velocity, grain size, fetch length, and underlying surface characteristics (Dong et al., 2002; Liu and Dong, 2004; Thomas et al., 2014). Average saltation height and decay rate both increase with wind velocity and fetch length (Dong, 2004). Sand transport at 0–2 cm height exceeds 50% of transport at 0–10 cm, indicating more saturated near-surface flux, active exchange on sand beds, and greater deposition near guardrails (Wu, 1987). Average saltation height increases to 2.72–5.17 cm between -7.0H and 20.0H, showing that subgrade surface sand flux is unsaturated due to insufficient sand supply, indicating saltation occurrence without active exchange with the subgrade surface. Airflow energy loss near guardrails is the primary cause of sand deposition.

In field tests, wind-blown sand flux structure shows that sand flux activity concentrates mainly in the near-surface 0–20 cm layer, consistent with Cheng et al. (2015). Due to scale differences, wind tunnel test sand flux characteristics differ from field observations. Additionally, the field sampler’ s lower chambers at 2.0, 5.0, 7.5, and 9.0 cm depths had a cross-sectional area of 1.7 cm × 1.7 cm. The sparse collector spacing and large chamber cross-section cannot accurately reflect near-surface wind-blown sand flux.

This study investigates sand deposition characteristics on the Bachu-Shache Desert Expressway. Field investigations show that wind-blown sand deposits mainly on the leeward side of guardrails in the overtaking lane. Wind tunnel test velocity characteristics reveal minimum wind velocity and lowest airflow energy at 3.5H. Desert expressway sand deposition patterns are consistent with these minimum velocity and airflow observations from wind tunnel tests.

5 Conclusions

Wind tunnel tests demonstrate that desert expressway subgrades produce two low-velocity zones: one on the windward subgrade side and another at the leeward subgrade foot. For subgrades with W-beam central guardrails, an increasing velocity zone forms above the guardrails while a decreasing velocity zone forms leeward. Maximum sand transport under subgrade influence concentrates between 3 and 5 cm above the subgrade surface, with particles uplifted by upward airflow and stronger rebound from the subgrade surface and guardrails. Field tests show that guardrails cause wind-blown sand deposition leeward of the guardrails in the overtaking lane, consistent with the minimum wind velocity location in wind tunnel tests.

This study clarifies interactions between W-beam central guardrails and wind-blown sand movement, but does not propose optimal guardrail types for desert expressways. Future research should focus on improving guardrail structure to reduce wind-blown sand impacts while meeting traffic safety infrastructure strength requirements for desert expressways.

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Note: Figure translations are in progress. See original paper for figures.