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Experimental Research on Sand Sediment Protection on Railway Tracks

Xingcai Li [1,2,*], Xuefeng Zhang [2,3], Fei Zhang [2] and Qianguo Liao [2]

1 Key Laboratory of Mechanics on Disaster and Environment in Western China, The Ministry of Education of China, Lanzhou University, Lanzhou 730000, China
2 School of Physics and Electronic-Electrical Engineering, Ningxia Key Laboratory of Intelligent Sensing & Desert Information, Ningxia University, Yinchuan 750021, China
3 China Telecom Shangqiu Branch, Cloud Network Operation Department, Shangqiu 476000, China
* Correspondence: nxulixc2011@nxu.edu.cn

Featured Application: A new method to effectively reduce sand accumulation on railway tracks.

Abstract: The wind-blown sand disaster on the railway has a very important negative influence on the economic development of traffic networks in desert areas. While there are some engineering protection measures for railway sand deposition, they are far from satisfactory in terms of economic efficiency and protection performance. Therefore, it is still of great practical significance to explore novel measures for actively preventing sand deposition on railway tracks in desert areas. In this article, the laws of sand deposition on single and dual tracks were studied with the help of field experiments. On this basis, it can be seen that the deposition of sand on the rear track can be effectively reduced by placing various types of baffles on the track. Field experiments were designed to study the change law of sand deposition ratio in front of the tracks caused by placing baffles of different cross sections. The results show that placing a 45° inclined baffle on the track can reduce the volume of sand deposition by up to 42%. The findings in this paper can provide scientific guidance for the design of new desert railways or novel protective measures for railway sand deposition.

Keywords: railway wind-sand disaster; actively preventing measures; inclined baffle; field experiments

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1. Introduction

The improvement of transportation network brings good opportunities for the development of regional economy and society. China has built the world's first railway around the Takla Makan Desert to promote economic development in Xinjiang (see Figure 1). However, the fact that wind-blown sand movement would jeopardize transportation facilities in deserts has been widely considered by people [1]. The accumulation of sand and dust particles on the desert tracks directly affects the safety of railway transportation, apart from decreasing the speed of railway transportation [2,3]. The sand intrusion can also have some negative influence on the dynamic mechanical behavior of railway ballast bed [4,5]. Therefore, it is of great practical importance to study a method for desert railways to prevent sand accumulation [6].

In order to control wind-blown sand damage on the railway track, some methods combining mechanical and biological elements are taken along railways [7]. For example, Reed, HDPE netting, asbestos tiles, pebbles, chemical materials, etc., have been used for sand stabilization. Moreover, desertification control grids, high vertical sand barriers, concrete walls and straw grids have also been used for desertification prevention [8–10]. The effectiveness and design methods of such engineering measures under different terrain conditions are increasingly becoming one of the interests for researchers [11–13]. For example, Zhang et al. [14] investigated the effect of near-surface airflow on Aeolian deposits across the Shapotou region's railway-protection system. Raffaele et al. [15] evaluated the protection efficiency of three methods, which contain the straight vertical wall, the shield for Sand rendering and the nylon net porous fence. The effect of fence porosity on the settlement of sand is investigated by Lavasani et al. [16], and they thought that the fence with 20% porosity is the best for reduction of sand deposition on railway tracks. Wang et al. [17] found the checkerboard sand barriers with enhanced checkerboard size and barrier height are needed to improve the efficiency of sand protection. Based on the comparison experiment, Gao et al. [18] found the cable guardrail should be preferred as a desert highway guardrail, followed by the W-beam guardrail and the concrete guardrail is unsuitable. Based on the field observation and indoor calculation, Xie et al. [19] suggested that the sand-controlling pattern should be dominated by sand blocking or fixing and combined with vegetation. The effect of fence porosity on reducing wind velocity and restraining wind-blown sand is investigated by Wang et al. [20] in the wind tunnel. Li et al. [21] suggested the biological sand control system should be used to provide sustainable protection for the desert highway. Of course, this method should also be extended to other situations. Shi et al. [22] performs a comparative evaluation of the straight or obliquely inserted concrete plates (SIP or OIP) sand-control fences through wind tunnel testing and field experiment, and they found that the OIP fence is more efficient for sand-retaining. Wang et al. [23] suggested the sand fence should be raised from the present 2–3 m. These studies provide important scientific support for optimizing the protective structure of desert railway, but the search for more efficient sand fences will not stop.

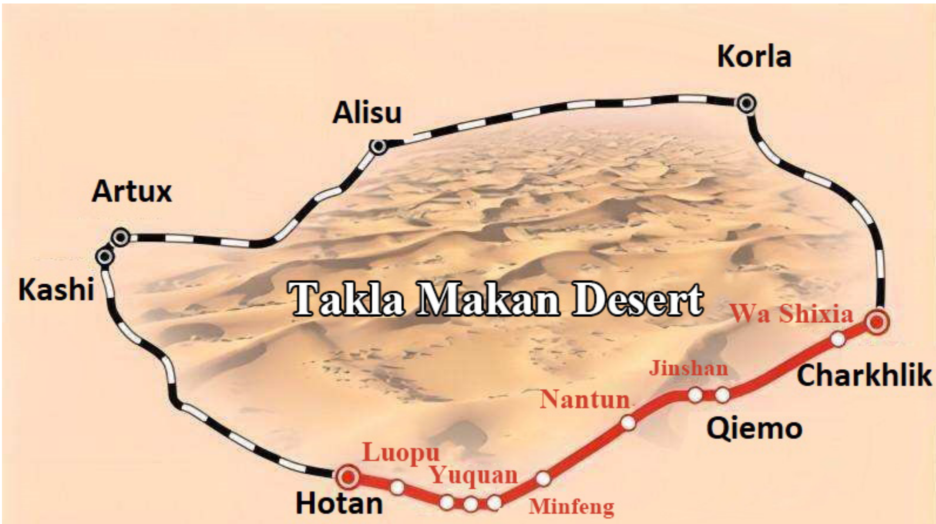

Figure 1. The railway around the Takla Makan Desert.

Understanding the local flow and sand deposition patterns around the railway track is a necessary prerequisite to prevent sand-induced limit states [17,24], and the numerical simulation is the most efficient option. With the development of computing technology, many scholars have studied the problem of railway sediment accumulation based on the computational fluid dynamics. Zhang et al. [25] simulated the movement of wind-blown sand around the high vertical sand barrier with HDPE panels, and they find when the distance between three HDPE sand barriers is set to be 30 m, it serves well as a sand-resisting measure or a sand-fixing measure. Huang et al. [26] discussed the law of sand particle accumulation over railway subgrade with wind-break wall. Mehdipour et al. [27] studied the sand protective efficiency of galleries based on 2D and 3D CFD models, and they propose new measures. Sarafrazi et al. [28] proposed some results to determine the proper distance of rigid wall barriers in desert areas according to the particle's size distribution and wind speeds. Zhang et al. [29] proposed a new preventive method by removing part of the ballast to decrease the sand deposition. Wang et al. [30] simulated the wind-blown sand movement over a sand dune with a railway in the reverse region, and studied its negative influence on the railway subgrade engineering and bridge engineering located on the sand dunes' leeward slope. Xin et al. [31] suggested to set up the second retaining wall on the leeward side of the existing wind-break wall to reduce sand sedimentation based on a wind-tunnel experiment. Dun et al. [32] studied the mechanism of sand sedimentation on the leeward side of three types of windbreak walls within different terrains. Li et al. [33] studied the responding law of the wind–sand flow to the embankment under different design parameters. Shu et al. [34] studied the effect of the dynamic windblown sand environment on the wear and damage of wheel–rail under different slip ratios. Of course, sand accumulation on the railway is not all harm. Under certain conditions, it may be beneficial. For example, Xie et al. [35] designed the experimental research on the Qinghai–Tibet Railway, and they found that sand sediment facilitates permafrost stability, which in turn can help promote safety in railway operations. Zhang et al. [4] found sand intrusion can reduce the vibration of the ballast bed.

The above introduction reflects that the research efforts regarding engineering facilities for sand deposition prevention have been dedicated toward improving the structure and layout of existing facilities. These efforts have improved the efficiency of sand deposition prevention to a certain extent, but are still far from solving the problem of sand deposition on railway tracks. In this sense, it is still of great significance to explore novel approaches to sand deposition prevention for railways. As a part of these efforts, a novel method to reduce the sand deposition on railway tracks is presented, which was realized by regulating the flow field on the track using the physical analysis of experiments on track sand deposition.

2. Single-Track Sediment Transport Experiment

2.1. Experiment Design

The field experiments were carried out in the Tengger Desert in Zhongwei City, Ningxia Hui Autonomous Region. The facilities and setup methods used in the experiment are shown in Figure 2. A mine fan (1100 W/50 Hz) was used to generate the wind field, and a frequency converter was used to change the fan speed, so as to control the wind speed. The track under the experiment was 90 mm high and 1000 mm long. Plastic tubes with an outer diameter of 30 mm and a length of 300 mm were used as sediment collecting devices, which were sealed at one end with paper and adhesive tape. The Rise2008 Laser Particle Size Analyzer produced by Jinan Rise Science & Technology Co., Ltd. (Jinan, China) was applied. The device uses a He-Ne gas laser source with a wavelength of 0.6328 µm and features good stability. Tests revealed that the wind produced by the fan was relatively stable at 170 cm away from the outlet, so the distance between the fan and the track was set as 170 cm. The six sediment collecting devices were positioned as indicated in Figure 1. Specifically, No. 1 sediment collecting device was located in front of the track, with its inlet 48 cm away from the track, which was used to measure the sediment load of incoming flow; the remaining five sediment collecting devices were located in the rear of the track, with their inlets 7 cm, 20 cm, 35 cm, 70 cm and 85 cm from the rear of the track. This arrangement was designed to measure the changes in sediment load when the incoming flow crossed the first rail. The wind speed of the incoming flow was regulated by the frequency converter. Five tests were conducted at wind speeds of 7.85 m/s, 7.64 m/s, 7.21 m/s, 6.72 m/s and 5.49 m/s during the experiment. The fan was started first and ran for five minutes, then the sand collected in the sediment collecting tubes was put into numbered ziplock bags for weighing in the laboratory after the experiment.

2.2. Results and Discussion

Figure 3 illustrates the change law of sand amount in the sediment collecting devices along the height direction under different wind speeds. From the figure, the sediment loads at No. 1, No. 5 and No. 6 sediment collecting devices decrease exponentially along the height direction, while those at No. 2, No. 3 and No. 4 sediment collecting devices are in unimodal distribution along the height direction, with one peak occurring within the height range of 120~150 mm. A similar distribution phenomenon was reported by Zhang et al. [36]. This mainly lies in the fact that the blocking effect of the track lifted the flow field to the rear of the track, making the sand transported with the wind jump higher and be transported further. In addition, the sand amount collected in the rear sediment collecting tubes increases continuously with increasing wind speed, indicating that wind speed is conducive to sediment transport. The unimodal distribution of sediment transport rate tends to disappear at the No. 4 sediment collecting tube, indicating that the lifting effect of the track on the flow field nearly disappears.

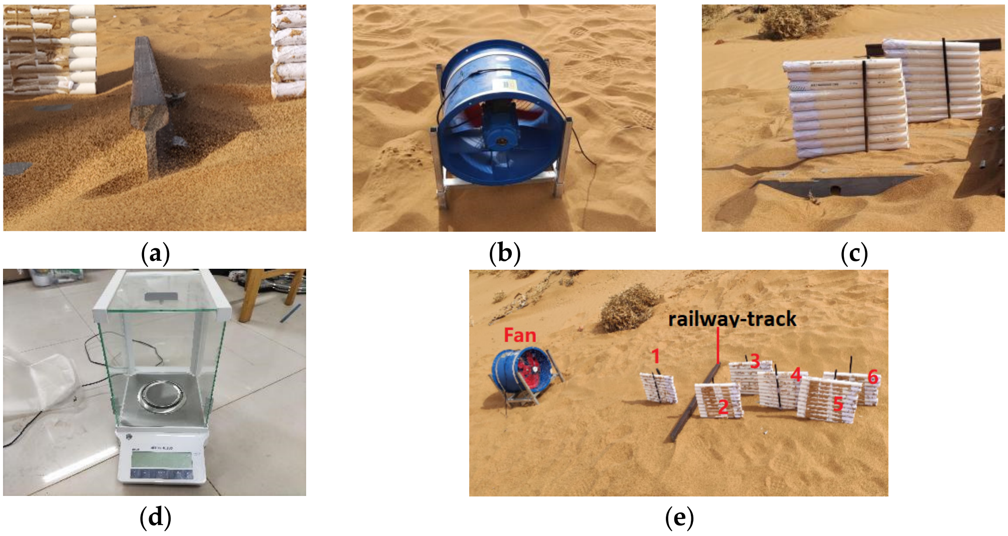

Figure 2. Sketches of the field experiment. (**a**) the track; (**b**) axial fan; (**c**) sediment collecting device; (**d**) electronic balances; (**e**) arrangement of experimental equipment.

The above results show that the disturbance of the track to the wind field changes the transport process of sand, which after leaping over the track, moves obliquely upward, inevitably increasing the saltation distance of the sand. However, as the flow field in the rear of the track recovers, the sand deposits at an accelerated pace under downward hydrodynamic action, resulting in the large amount of sediment in front of the second rail. The mechanism can explain the natural sand deposition as shown in Figure 4. Therefore, if the flow field can be lifted again at the No. 4 or No. 5 sediment collectors, it would be possible to reduce the sand and dust deposition on the rear of the track.

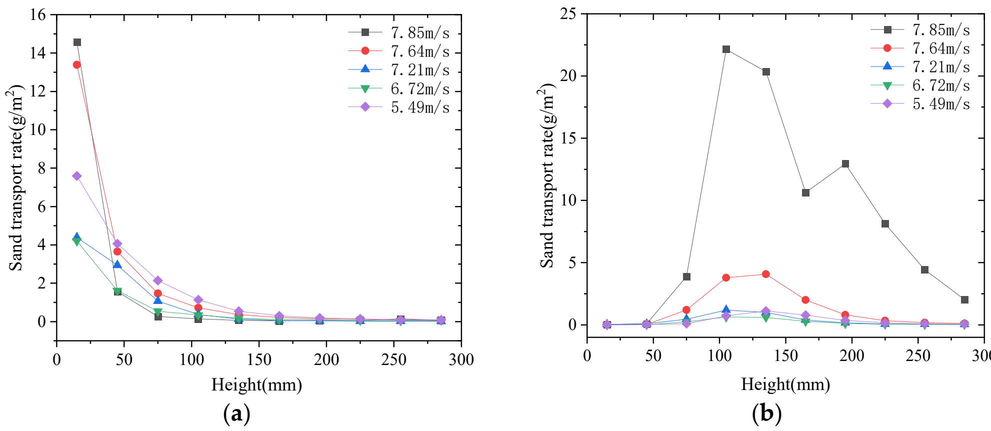

Figure 3. *Cont.*

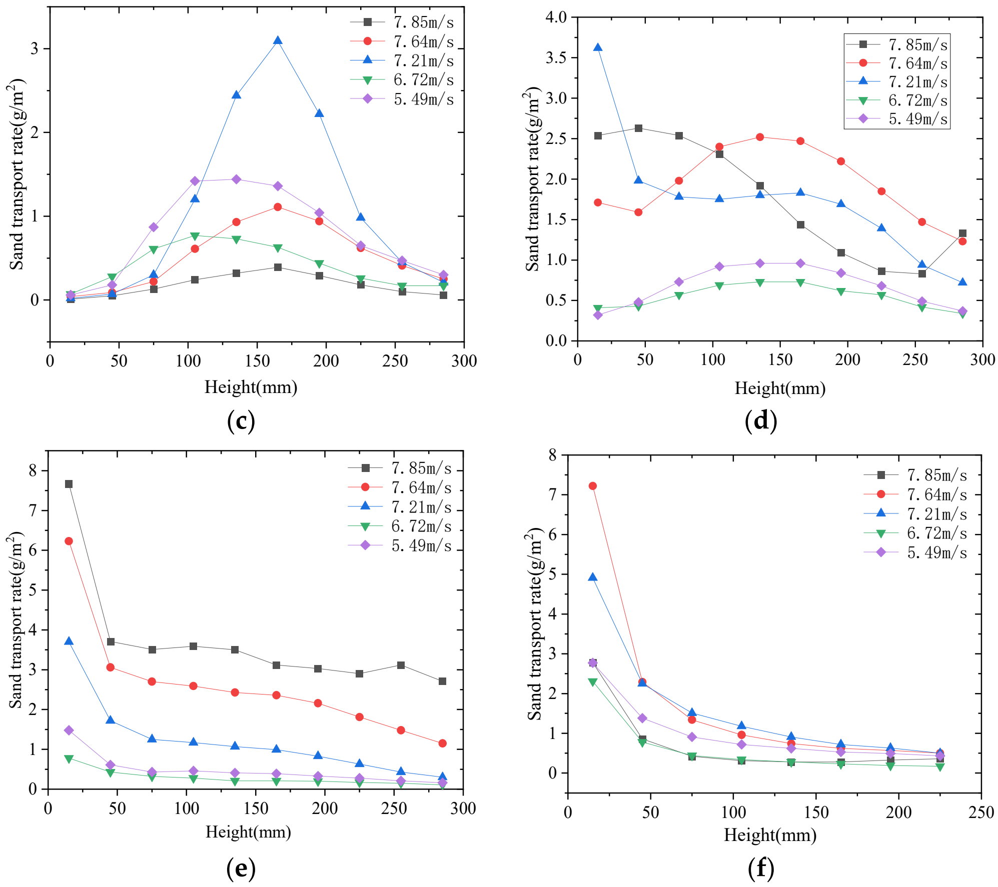

Figure 3. The sand transport rate of each sediment collecting device. (**a**) No. 1 sediment collecting device; (**b**) No. 2 sediment collecting device; (**c**) No. 3 sediment collecting device; (**d**) No. 4 sediment collecting device; (**e**) No. 5 sediment collecting device; (**f**) No. 6 sediment collecting device.

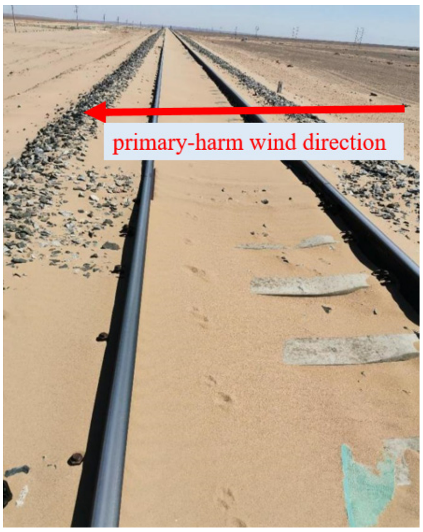

Figure 4. The distribution of sand sedimentation on Harrow Railway.

3. Dual-Track Sand Deposition Experiment

3.1. Experiment Design

In order to investigate the distribution of sand deposition on the railway track under the same conditions, a railway model with two small tracks was developed. Considering the significant height difference between the track used in the experiment and the actual track, the rail gauge of the two tracks was proportionally scaled in the field experiment. The standard rail gauge is 1435 mm, but in this experiment, the rail gauge was set to 730 mm. For the sake of simplicity, the two rails were numbered and defined as the "first track" and the "second track" along the direction of incoming flow. Experience shows that in the case of wind-drift sand flow, sand may mainly deposit outside the first track and inside the second track along the direction of incoming flow. Therefore, after track setup two laser rangefinders were fixed on the supports (the supports were placed on one side of the experimental track so as not to affect sand deposition) to measure the sand deposition in front of first track and in front of second track along the direction of incoming flow. Relevant experimental facilities and the setting are shown in Figure 5. The laser rangefinders have a range resolution of 4 mm, measurement range of 0–10 m and precision higher than 4%. The experiment lasted about 20 min. The laser rangefinders measured the range data three times per second, which means the sampling frequency was 3 Hz. This experiment was carried out under natural wind conditions, with a wind speed of about 10 m/s.

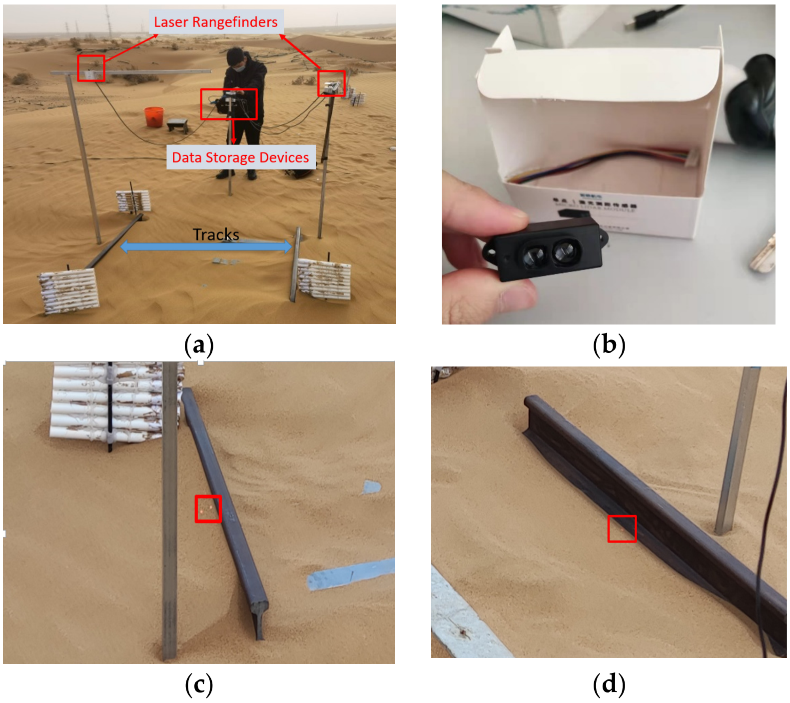

Figure 5. Scene of field experiment based on laser ranging. (**a**) field experiment; (**b**) laser rangefinders; (**c**) measurement point for the first track; (**d**) measurement point for the second track.

3.2. Results and Discussion

The experimental results are shown in Figure 6. In the figure, the black line represents the sand deposition velocity in front of first track. It can be seen that the sand deposits fast, and can reach a height of 60 mm in about 250 s, equivalent to 14 mm per min. After that, the deposition velocity tends to increase slowly. The red line represents the sand deposition velocity in front of second track. The figure shows that the sand deposits stably, and can reach a height of about 45 mm in 15 min, equivalent to 3 mm per min.

Moreover, in the curves of sand deposition height in front of first and second tracks, the first sudden change was observed at the node time of about 250 (corresponding to about 80 s), the second sudden change at the time mark of about 500 (corresponding to about 167 s) and the third sudden change at the time mark of about 600 (corresponding to about 200 s). After that, the height of deposited sand on the front track gradually fluctuates in a small range, while that on the rear track increases at a decreasing rate, till both tracks have the same sand deposition height. The track section at this point is defined as a "stabilized section". This phenomenon indicates that the sand deposition velocity on the rear track will change with the volume of sand deposition on the front track. In this regard, the slope changes of the experimental data were investigated before the three nodes after linear fitting, as shown in Table 1 below. It can be observed from the table that the velocity of sand deposition on the front track gradually decreases; while that of the rear track decreases first, then increases and finally decreases over time, with the velocity in the third section exceeding that in the first section. Please note that the third section corresponds to the section where the sand deposition on the front track tends to be saturated. In the meantime, the sand deposition velocity on the rear track increases significantly, and the sand deposition here tends to become saturated quickly. This phenomenon shows that, curbing the sand deposition on the front track could possibly abate the sand deposition on the rear track, to the extent that the flow field on the track will not be affected. This is mainly due to the obvious lifting effect of the front track on the flow field, which can effectively increase the height and distance of sand saltation. This result is consistent with the experimental results in the previous section.

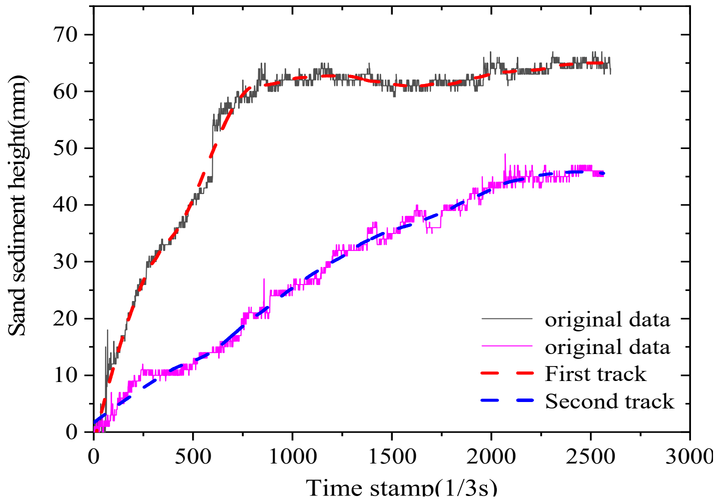

Figure 6. Variation of sand deposition volume on railway tracks.

Table 1. Slope variation of curves of sand deposition height on the front of tracks.

Position	First Section	Second Section	Third Section	Stabilized Section
Front Track	0.113	0.052	0.015	0.004
Rear Track	0.024	0.012	0.027	0.014

4. Experiment on Sand Deposition on the Tracks

4.1. Experiment Design

Based on the above experimental results, the conclusion can be drawn that placing an object in an appropriate position on a track could lift the wind field on the track for the second time, thereby significantly reducing the volume of sand deposition on the track. Therefore, a field experiment under natural winds was conducted to verify it. However, considering that the speed and direction of natural wind fluctuates frequently, and the track used is merely 1.1 m long, it is difficult to obtain a unified law of sand deposition on the track. Therefore, a simple wind tunnel was set up to prevent the diffusion of wind speed in the experimental section on the one hand, and to reduce the disturbance of natural wind on the experimental section so as not to affect the results, on the other hand. The wind tunnel has a 115 cm × 65 cm rectangular section. The wall of the wind tunnel is made of 1.8 cm thick composite boards, which are free from obvious warping. The fan is composed of two 220 V 50 Hz cleaning fans with a rated power of 1000 W. A frequency modulator can also be used to regulate the experimental wind speed. The air outlet of the fan at the bottom is placed slightly downward to ensure sufficient sand source. A fan located above the side provides a horizontal force for the blowing sand and making it move horizontally. The setup of experimental facilities and data acquisition methods are shown in Figure 7.

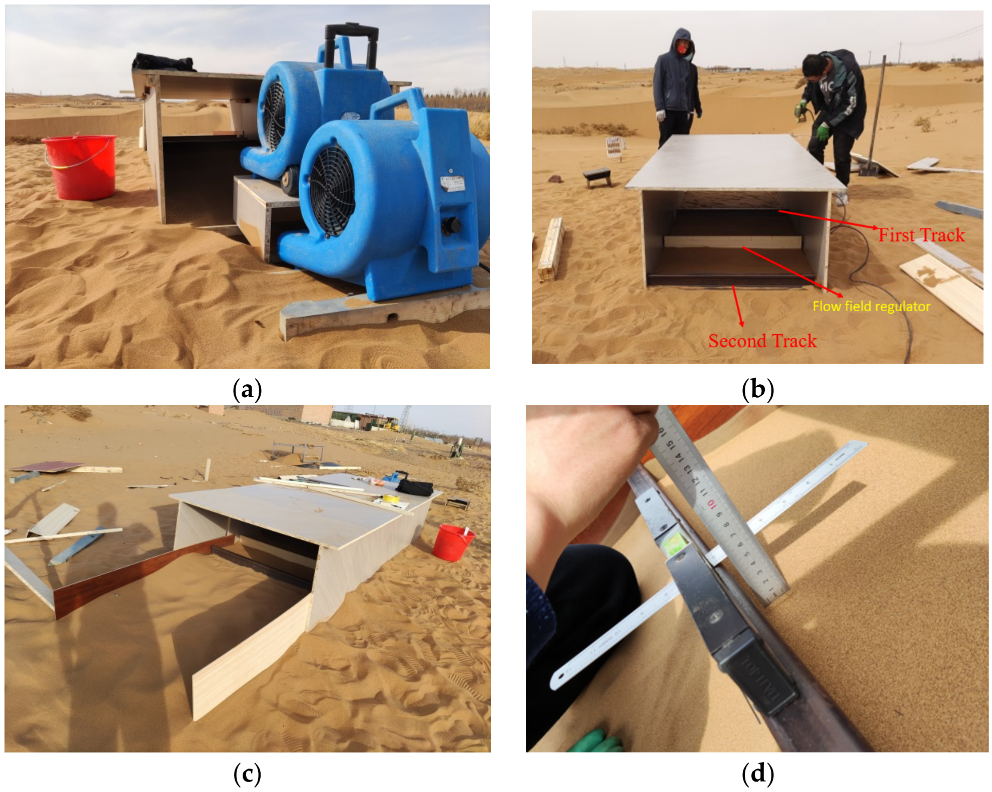

Figure 7. Schemes of Field Experiment Based on Simple Wind Tunnel. (**a**) simple experimental wind tunnel; (**b**) arrangement of the experimental devices; (**c**) general view of the experimental setup; (**d**) measurement of sediment height.

The experiment steps are as follows:

(1) Place the track and calibrate its height with a level gauge to make sure the track is basically at the same level. Measure and record the height of the track exposed above the sand surface;

(2) Start the fan and the experiments on track sand deposition. The sand blowing time was set to 8 min after tests. The reason lies in the fact that a short sand blowing time may be associated with an unsatisfactory sand deposition effect, which is unfavorable for measuring the height of deposited sand. In contrast, if the sand blowing time is extremely long, the front track will be covered by too much sediment, while the sand will keep depositing on the rear track, which makes the height data of deposited sand invalid;

(3) After 8 min of the experiment, turn off the fan, measure the heights of sand deposited on the front and rear tracks, and keep records;

(4) Place baffles with different cross sections on the track, repeat the above steps and record the measurement results;

(5) Repeat the above experiment twice, and analyze the data.

4.2. Results and Discussion

The experiment results are shown in Table 2. It can be seen that during the 8 min sand deposition period, the height of deposited sand in front of the tracks under experiment are slightly different. This may be explained by the different dust emission amounts in the experiment. Nevertheless, the ratio between the heights of deposited sand on the front (first) and rear (second) tracks is relatively stable. Therefore, the ratio between the heights of deposited sand on the front and rear tracks was used to characterize the sand prevention effect of the baffles, defined as "sedimentation height ratio". Additionally, unless otherwise specified, the heights of the square timbers or inclined baffles placed on the tracks should be the same as the height of tracks, and both heights should be calibrated with a level gauge.

Table 2. Field experiment results.

	Sedimentation Height of First Track (cm)	Sedimentation Height of Second Track (cm)	Sedimentation Ratio
Original Track	7 4.7	3 1.9	0.43 0.40
Square wood	7.7 8.1	2.3 2.7	0.30 0.33
45° inclined Baffle	6.2 7.8	2 2.5	0.32 0.32
45° inclined Baffle 2 cm Higher than the Track	7.7 7.3	1.8 1.8	0.23 0.25

According to relevant railway standards, on railway tracks, safety distance is defined as a distance not greater than 25 mm above the tracks. Thus, in the experiment, the height ratio of deposited sand between the front and rear tracks was measured when the baffles were installed 20 mm higher than the track. The results of relevant data are listed in Table 2. From the table, the ratios between the heights of deposited sand are 0.43 and 0.40, with the mean value of 0.415 in the case of the original track, and 0.30 and 0.33, with the mean value of 0.315 when installing a square timber with a width of 115 mm the same height as the track. The height of sand deposited decreases by about 24.1%, which shows that installing a square timber the same height as the track can effectively reduce the sand deposited on the rear track. However, square timbers helped curb the sand deposition on rear track, but sand deposited heavily in front of the square timbers. This indicates that square timbers can improve the sand deposition on the rear track, but aggravate the sand deposition in the front part of the tracks. Then, baffles with different inclination angles were placed in the track. First, a 45° inclined baffle, with a length of 100 mm on two right angled sides and 141 mm on hypotenuse side, and the same height as the track, was placed on the track, which produced a sand deposition ratio of 0.32. Obviously, this result is almost the same as that produced by the square timber approach, indicating that the two approaches have basically the same effect on the sand deposition velocity on the rear track, except that inclined baffle would result in less sand deposition in the front as compared with square timber, so the inclined baffle outperforms the square timber in terms of sand prevention effects. Since a train can travel safely over objects placed within 25 mm above the track, the height of the inclined baffle can be increased as a whole. For the sake of safety, the device was lifted 20 mm and the experiment was repeated. It was found that after the placement of the 45° inclined baffle, the sedimentation height ratio between the front and rear tracks was 0.23 and 0.25, with the mean value of 0.24. Compared with the original track, the sand deposition on the rear track decreased by 42.2%, which is comparable to the results present by Xin et al. [31] on the sand prevention efficiency of desert railways. However, the method proposed in this paper has lower construction cost.

The field experiment was accidentally interrupted due to the need of COVID-19 epidemic control, so a simulation experiment was conducted in the laboratory to supplement the changes of sand deposition on the front and rear tracks when various baffles with different inclined angles and heights were placed in the tracks. See Figure 8 for the experimental setup and Table 3 for the experimental results.

Figure 8. Laboratory experiment for preventing sand deposition on railway tracks.

Table 3. Laboratory result.

	Front Track (cm)	Rear Track (cm)	Height Ratio
Original Track	6.2	2.1	0.34
30° Inclined Baffle	6.2	1.3	0.21
30° Inclined Baffle, 2 cm Higher than the Track	6.2	1.2	0.19
45° Inclined Baffle	6.2	1.0	0.16
45° Inclined Baffle, 2 cm Higher than the Track	6.2	0.9	0.15
60° Inclined Baffle	6.2	0.8	0.13
60° Inclined Baffle, 2 cm Higher than the Track	6.2	0.7	0.11

As can be seen from Table 3, the sand deposition ratio was 0.34 on the original track, 0.21 after placing a 30° inclined baffle the same height as the track (reduced by 38.2%), 0.19 after raising that baffle height by 2 cm (reduced by 44.1%); 0.16 after placing a 45° inclined baffle the same height as the track (reduced by 52.9%), 0.15 after raising that baffle height by 2 cm (reduced by 55.88%); 0.13 after placing a 60° inclined baffle the same height as the track (reduced by 61.76%), 0.11 after raising that baffle height by 2 cm (reduced by 67.6%). It can be seen that the preventive effect of a baffle on the sand deposition on the rear track improves by increasing the inclination angle and height of the baffle, indicating that proper increase of baffle height is more conducive to reducing sand deposition on the rear track. In the future, it is possible to try to develop larger wheels for low-speed trains in desert areas, so as to raise the bottom height of the vehicle. This condition can increase the height of the sand baffle to achieve the best sand protection efficiency.

5. Conclusions

In this paper, the laws of sand deposition on single-track and double-track railways were explored using field experiments and laboratory simulation experiments. The results show that:

(1) The track can lift the flow field in the rear, and lead to a significant change in the sand saltation height and distance.
(2) Along the direction of incoming flow, the volume of sand deposition in front of the first track directly affects the volume and velocity of sand deposition in front of the second track, indicating that the sand deposition on the rear track can be effectively abated by controlling the sand deposition on the front track.
(3) The sand deposition on the rear track can be effectively reduced by placing different types of baffles in the track. During the same period, placing a 45° inclined baffle exerted the best preventive effect on the sand deposition on the rear track.

It should be noted that there are significant differences between laboratory data and field data, but the laws revealed should be similar. The findings in this paper are of important reference significance for the design of new desert railways or novel protective measures for railway sand deposition.

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