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Shelter effect efficacy of sand fences: A comparison of systems in a wind tunnel

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ABSTRACT

The Lanzhou-Xinjiang High-speed Railway runs through an expansive wind area in the Gobi Desert and blown-sand disasters are a critical issue affecting its operation. To strengthen the blown-sand disaster shelter systems along the railway, the shelter effects of punching plate and wire mesh fences with approximately equal porosity (48%) were simulated in a wind tunnel. The experimental results showed that the wind velocity was reduced to a higher extent by the punching plate fence than by the wire mesh fence. When a single row of sand fencing was used, the wind velocity reduction coefficient (Rc_z) values downwind of the punching plate fence and wire mesh fence reached 71.77% and 39.37%, respectively. When double rows of sand fencing were used, the Rc_z values downwind of the punching plate and wire mesh fences were approximately 87.48% and 60.81%, respectively. For the flow field structure on the leeward side of the fencing, the deceleration zone behind the punching plate fence was more pronounced than that behind the wire mesh fence. The vortex zone was not obvious and the reverse flow disappeared for both types of fences, which indicates that the turbulent intensity was small. The sand-trapping efficiency of the wire mesh fence was close to that of punching plate fence. When a single row of sand fencing was set up, the total mass flux density decreased, on average, by 65.85% downwind of the wire mesh fence, and 75.06% downwind of the punching plate fence; when double rows of sand fencing were present, the total mass flux density decreased, on average, by 84.53% downwind of the wire mesh fence and 84.51% downwind of the punching plate fence. In addition, the wind-proof efficiency and the sand-proof efficiency of the punching plate fence and the wire mesh fence decreased with increasing wind velocities. Consequently, punching plate and wire mesh fences may effectively control the sand hazard in the expansive wind area of the Gobi Desert.

1. Introduction

Sand fences are typically used to reduce wind velocity and restrain windblown sand particles. These fences are one of the most important pieces of equipment in blown-sand disaster shelter systems. They can be upright, horizontal, griddled, holed-plank, or wind-screened, depending on the materials available in different areas (Dong et al., 2007). For example, upright fences made of reed bunches are used along the highway that crosses China's Taklamakan Desert (Dong et al., 2004). Nylon net fences are used along the Qinghai-Tibet Railway (Zhang et al., 2010; Cheng and Xue, 2014) and on the top of Mogao Grottoes, China (Ling et al., 1996; Wang et al., 2005). The aerodynamic characteristic and shelter effect of a sand fence depends on its geometric design, including height, length, width, porosity, and opening size, distribution, and geometry (Li and Sherman, 2015). Porosity is commonly considered the most important structural feature controlling the performance of a sand fence and is defined as the ratio between the open area of the fence and its total area (Bean et al., 1975; Cornelis and Gabriels, 2005). In general, the optimal porosity of a sand fence is considered to range from 30 to 50% (Ling et al., 1984; Lee and Kim 1998, 1999; Lee et al., 2002; Cornelis and Gabriels, 2005; Dong et al., 2006, 2007), and there is no reverse flow present behind the fence when the porosity is greater than 40% (Lee and Kim, 1999). The geometry, size, and distribution of the openings within a fence have relatively small, but non-trivial influences on wind velocity reduction and sand-trapping efficiency compared to the fence porosity (Li and

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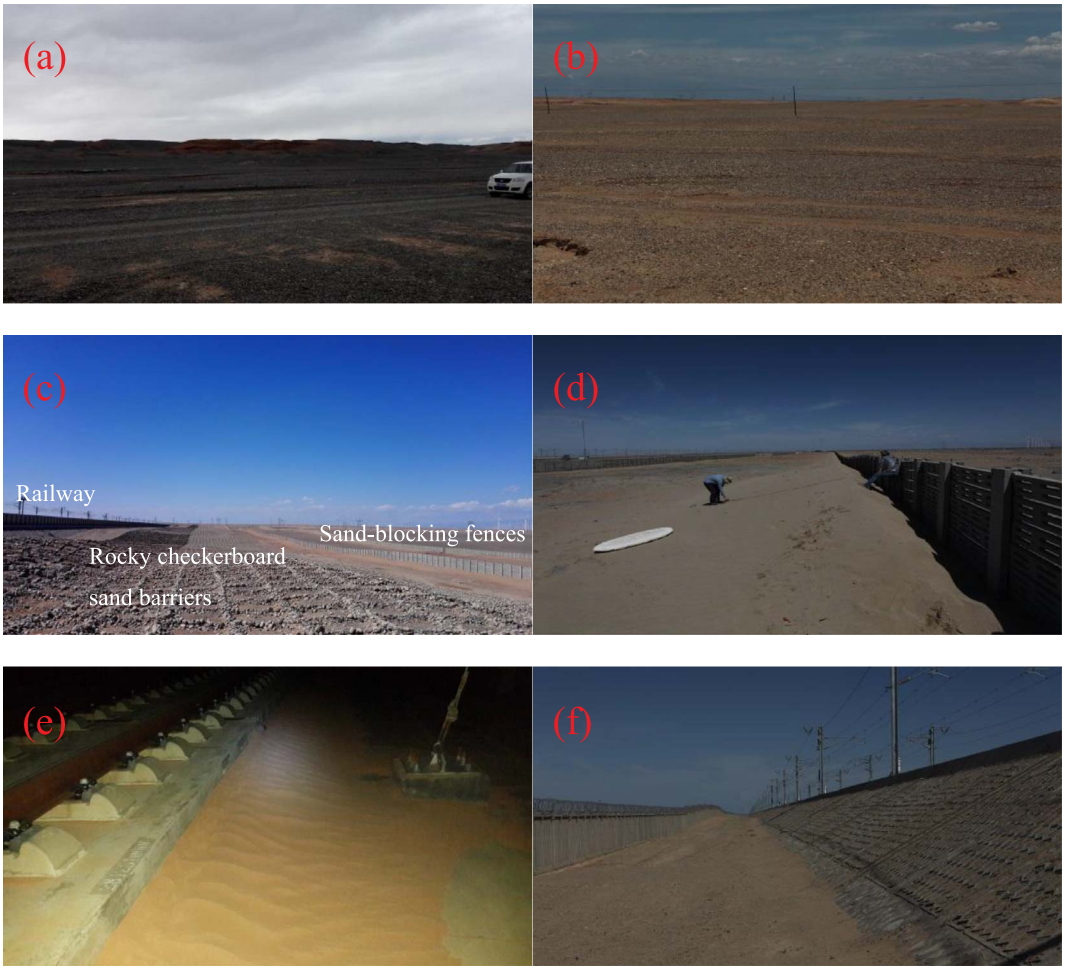

Fig. 1. Photos of the study area. (a) Gobi Desert surface in the 'Hundred Miles' wind area; (b) Gobi Desert surface in the 'Yan Dun' wind area; (c) Blown-sand disaster shelter systems built upwind of the railway; (d) Sand accumulations downwind of the sand fence in Yandun in the 'Yan Dun' wind area; (e) Sand accumulations around the rail bed in Hongceng in the 'Hundred Miles' wind area; (f) Sand accumulations around the foot of the subgrade slope in Yanquan in the 'Yan Dun' wind area.

Sherman, 2015). For fences with the same porosity, the sand-trapping efficiency decreases as the opening size increase (Savage, 1963; Savage and Woodhouse, 1968; Manohar and Bruun, 1970), and fences with round edges (e.g., circular holes) have a lower trapping efficiency than those with sharp-edges (e.g., square holes, vertical slits, or horizontal slits) (Li and Sherman, 2015). In addition, the influence of a fence on a local wind regime will also depend on environmental conditions, which include incoming flow conditions, local topography, and sedimentology (Li and Sherman, 2015).

The Lanzhou-Xinjiang High-speed Railway is the first high-speed railway that runs through expansive wind areas, which includes 'Yan Dun', 'Hundred Miles', and 'Thirty Miles' wind areas from east to west. The expansive wind area the railway passes through is as great a distance as 462.41 km in Xinjiang (Zhou et al., 2012; Cheng et al., 2016). The maximum wind velocity recorded was 60.2 m/s in the 'Hundred Miles' wind area, 56.6 m/s in the 'Thirty Miles' wind area, and 42.3 m/s in the 'Yan Dun' wind area (Cheng et al., 2015). These areas of expansive wind along the Lanzhou-Xinjiang High-speed Railway are predominantly found in the Gobi Desert (Fig. 1a and b), which has fragile natural conditions. Therefore, blown-sand disasters are the main problems concerning the railway operation (Cheng et al., 2016, 2017). Especially in the 'Yan Dun' wind area, which the sand source is more abundant than in the other two wind areas.

To protect the rail bed from destruction by windblown sand, a mechanical blown-sand disaster shelter system has been created on the windward side of the railway. The shelter system primarily comprises plank-type sand fences and rocky checkerboard sand barriers (Fig. 1c). The existing plank-type sand fences along the Lanzhou-Xinjiang High-speed Railway are constructed of concrete slabs and have large uneven openings (the rectangular pore size is 27.5 × 3 cm). The proper opening size of the sand fence is smaller than 10 times the sand diameter (Hotta et al., 1987); thus, the large opening size and uneven opening distribution of the plank-type sand fences decreases its sand-trapping efficiency. A fraction of the sand particles pass through the openings and are carried to the subgrade of the railway. In addition, the plank-type sand fences have a relatively low porosity (approximately 30%). This diminishes the intensive wind, but it also creates more turbulence downwind of the fences (Cheng et al., 2016). The intensive turbulence produced by the low-porosity fence may result in increasing horizontal wind velocities closer to the fence, possibly matching the speeds of the upwind velocities and, consequently, decreasing the effective shelter distance (Lee and Kim, 1999; Cornelis and Gabriels, 2005; Dong et al., 2007). The unsound structure design of the plank-type sand fences have resulted in sand accumulation close to the fence and fence buried (Fig. 1d). Therefore, the shielding effect of the blown-sand disaster shelter system is not optimal because windblown sand particles accumulate around the railroad and the foot of the subgrade slope (Fig. 1e and f). High vertical-type nylon net sand fences used on the top of Mogao Grottoes have a small opening size and evenly distributed openings, which have proved effective for sand control over the surface of Gobi Desert (Qu et al., 2002; Wang et al., 2005; Stone, 2008). However, these nylon net fences are easily damaged by high winds, and therefore cannot be used in the expansive wind area. Consequently, to strengthen the existing blown-sand disaster shelter system along the