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Wind energy environments and aeolian sand characteristics along the Qinghai–Tibet Railway, China

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ABSTRACT

The Qinghai–Tibet Railway (QTR), the longest high-altitude railway in the world, is frequently damaged by windblown sand because of strong winds and abundant sand. Based on detailed wind data, in situ observations of windblown sand and field wind tunnel simulations along the QTR, this paper aims to clarify the characteristics of windblown sand with increasing altitude, and to show the dynamical environment of sand activities. The predominant wind is unidirectional along the QTR. In cold-high environments, sand transport rate increases with increasing wind velocity, but decreases exponentially with increasing height in the windstream. As the altitude increases, the threshold velocity for sand movement linearly increases with altitude, and the sand transport per unit width decreases gradually. The results can be used to guide the design of sand-control structures both in the study area and in other areas suffering from windblown sand.

1. Introduction

The Qinghai–Tibet Railway (QTR), with a total length of 1956 km, is the longest high-altitude railway in the world (Peng et al., 2007; Qiu, 2007). It runs from Xining to Lhasa and consists of two sections according to their time of completion (Fig. 1). The first section from Xining to Golmud was finished in 1984 and named the Xigo Section. The second section from Golmud to Lhasa is called the GoLha Section and was completely open to traffic in 2006.

The QTR runs through the Qinghai–Tibet Plateau, which presents typical characteristics of high-cold and arid environments (Wu et al., 2003; Yang et al., 2004). Under the influence of subtropical westerlies, the Qinghai-Tibet Plateau frequently undergoes strong windy days (with instantaneous velocities of >17 m s^{-1}). Bai et al. (2005) reported that more than 60 days have strong winds per year in most regions of the Qinghai-Tibet Plateau. Especially in the Tuotuohe region along this railway, strong windy days are in excess of 100 annually. Annual precipitation is about 200 mm and 85% of it is concentrated in summer. It rarely snows in winter, when it is arid and windy. Moreover, the soil structure is fragile and vegetation is sparse (Wang, 1997; Yan et al., 2001; Zou et al., 2002; Zhang et al., 2003; Xu et al., 2006). Therefore, sand damage occurs easily and frequently along the QTR during winters.

The QTR passes through a 550-km-long permafrost belt in the Kunlun and Tanggulha Mountains (Xie et al., 2012). The landforms along the GoLha Section of the QTR are very complex, including aeolian hills, mobile dunes, gravel deserts and alpine meadows. Now that the railway is completely open to traffic, sand damage has become a serious problem in this section due to the unique alpine sandy environment and strong winds (Zhang et al., 2010).

Generally, the occurrence of sand damage is dependent on three factors: arid climate, strong winds and abundant sand availability. Up to 2008, the portion of the railway affected by sand damage is about 270 km long, which accounts for one-fourth of the total length of the GoLha Section (Fig. 2). The railway length with severe, moderate and slight degree of sand damage is 43, 55 and 170 km, respectively.

The altitude is more than 4000 m above sea level in most regions of the GoLha Section. Air pressure at this altitude is only 60% of that at sea level and air density is also lower than that of surrounding plains. The characteristics of wind-blown sand along the QTR are different from other inland sandy regions because air pressure is a determinant of aeolian processes (Bagnold, 1941).

On the basis of meteorological data, in situ observations and mobile wind tunnel experiments, the aim of this study is firstly to describe wind environments along the QTR, and then clarify the characteristics of wind-blown sand on the Qinghai-Tibet Plateau. The results of this paper will be useful to further reveal the mechanisms of sand damage to the railway and to clarify the behavior of wind-blown sand in high-cold environments.

2. Materials and methods

To investigate the behavior of windblown sand in cold-high environments, we conducted simulation experiments using a mobile

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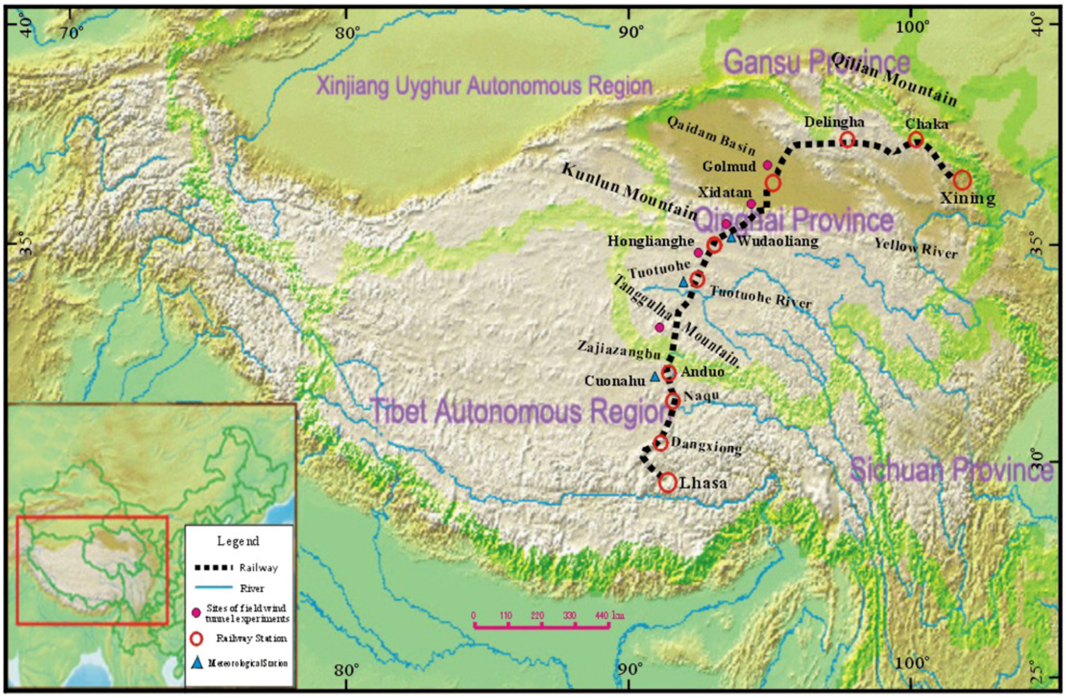

Fig. 1. Schematic route of the QTR, central China.

wind tunnel of the Key Laboratory of Desert and Desertification, Chinese Academy of Sciences (Fig. 3A). The blow-type non-circulating wind tunnel has a total length of 11.4 m and is composed of an entrance section (0.6 m), power section (1.2 m long), an expansion section (0.8 m long), a stabilization section (0.5 m long), a compression section (1.3 m long), a working section (6.0 m long) and a diffusion section (1.0 m long). The 6.0 m long working section has a cross-sectional area of 60 cm by 60 cm. Wind speed can be changed continuously from 0 to 20 m s^{-1}, and the thickness of the boundary layer in the working section can reach 23 cm. During experiments, free-stream wind velocities of 10, 11, 13, and 14 m s^{-1} were used. Wind velocity was measured by using an "X"-type sand-proof Pitot-static probe with a measurement error of less than 0.15% (Dong et al., 2002). The vertical distribution of blowing sand was measured by using a sand trap with a height of 40 cm and a width of 2.0 cm. The sand trap was set 5.0 m downwind from the entrance of the working section in the wind tunnel. The bottom of the lowest opening of the sand trap was set flush with the upwind sand surface. Sampling time ranged from 1 to 8 min, depending on the wind velocity (the lower the wind velocity, the longer the sampling time). The sand trap was removed after the experiment and the collected sand was measured by using an electronic balance (resolution of 0.001 g). Sand used in the wind tunnel experiments to create the sand bed was collected near the railbed at the Xidatan and it is mainly composed of silt, fine, very fine and medium sands. Silt accounts for 0.87%, fine sand 82.67%, medium sand 7.10% and very fine sand 9.37%. The median diameter is 0.19 mm.

Fig. 2. Typical damage caused by windblown sand along the QTR at (A) Xiushuihe, and (B) Cuonahu.

To ensure complete development of a wind–sand flow, a 6-m-long by 3-cm-thick by 60-cm-wide sand bed was prepared in the working section. Sand was replenished after each trial. According to the variation of altitude along the QTR, the mobile wind tunnel experiments were performed in four sites, at Golmud (with an altitude of 2900 m a.s.l. and air pressure of 726 hPa), Xidatan (with an altitude of 4100 m and air pressure of 628 hPa), Honglianghe (with an altitude of 4650 m and air pressure of 588 hPa) and Tanggulha (with an altitude of 5100 m and air pressure of 552 hPa).

Along with the wind tunnel experiments, the field wind velocity profile was also obtained at the same site, with the observed heights at 30, 50, 70, 90, 110, 130, 150, 170, 190, and 210 cm above the surface (Fig. 3B). Wind velocity profiles were measured by a wind mast for each run by using 10 rotating cup anemometers, at an interval of 3 s. The cups rotate on arms, and operate a reed switch whose