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The sand-damage–prevention engineering system for the railway in the desert region of the Qinghai-Tibet plateau

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ABSTRACT

The Qinghai-Tibet Railway (QTR) is the longest high-altitude railway in the world, which is frequently damaged by windblown sand. In order to prevent the sand damage, we constructed a sand-damage–prevention engineering system along the QTR. This was the first time a windblown-sand-prevention system was constructed in such a high-cold and arid environments; because of this, our work necessitated adjustments during the application of a number of different sand-damage–prevention engineering techniques. Based on detailed wind data and in situ observations of windblown sand, as well as systematic field measurements along the QTR, these sand-damage–prevention engineering measures were evaluated quantitatively and semi-quantitatively in this study. The results can be used to guide the design of sand-control structures, improve the existing sand-damage–prevention engineering system and optimize the structural performance of various sand-damage–prevention engineering measures.

1. Introduction

China has the longest railway line in the world that is threatened by windblown sand. About 10,000 km of railway lines which account for about 12% of total railway lines go through desert and aeolian sand regions in China, and thus are threatened by windblown-sand damage (Cheng et al., 2012). Among those is the Qinghai-Tibet Railway (QTR), which undergoes some of the most serious windblown-sand damage (Xu et al., 2006). The QTR, which is the longest high-altitude railway in the world, runs through the Qinghai-Tibet Plateau, from Xining to Lhasa. It is about 1956 km long and consists of two sections—the XiGo Section (from Xining to Golmud) and the GoLha Section (from Golmud to Lhasa). While the XiGo Section was built in 1979 with a relatively well-equipped windblown-sand-prevention system, the GoLha Section was completed and put into service in 2006 (Zhang et al., 2010).

The Qinghai-Tibet Plateau frequently experiences strong windy days (Bai et al., 2005), and some sections along the QTR experience in excess of 100 of these days per year. According to wind observation data collected by the Fenghuoshan observation station, in recent years the maximum wind speed and the instantaneous extreme wind speed in Fenghuoshan Mountain region have reached 20.4 m/s and 30.2 m/s (both on February 10, 2010), respectively. The landforms of the QTR are mostly alluvial formations, proluvial formations, and river valleys, which are all characterized by a loose earth surface and sparse vegetation (Belnap and Gardner, 1993), both of which provide a rich material for windblown-sand damage. With the GoLha Section of the QTR going into service, the windblown-sand damage problem in this region has intensified. In order to address this serious issue, multiple sand-damage–prevention engineering measures have been employed along the QTR, and many have been highly effective. To evaluate these, researchers have conducted a series of studies on the near-surface wind regime, wind energy environments, and the status of windblown disaster regions with respect to windblown sand damage (Niu et al., 2009; Zhang et al., 2012).

Meanwhile, a number of Chinese scientists have started studies on sand prevention and control measures along the railway. Current studies focus on the sand-control efficacy of single-sand prevention and control measures (Cao, 2003), while comprehensive sand-prevention studies have not been reported. Outside of China, studies of sand disaster along railway lines mainly concentrate on two aspects. One concerns railway damage from windblown sand (Esmaeili et al., 2013). Studies on this have shown that sand damage has various harmful effects on conventional ballasted tracks. The second aspect is a prevention measure that involves the control of sand damage; the goal in this case is to avoid active areas of wind-sand flow when designing the railway route (Zakeri and Forghani, 2012; Zakeri et al., 2011). When it is unavoidable to do so, the structure of the railway sleeper should at least be adjusted. The space between the railway and the sleeper should be large enough so that the wind-sand flow is free to pass through, instead of depositing on the track. However, this type of sand-prevention system has not been studied thoroughly to determine its efficacy (Jabbar and Abbasi, 2012; Jabbar, 2012).

Since this was the first time a windblown-sand-prevention system was built in such a special environment, the process of

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applying sand-damage–prevention engineering measures is, out of necessity, a process of continuous attempt and improvement. As indicated by field surveys, many existing measures either failed to satisfy the windblown sand-damage–prevention need, or could not bring their windblown-sand-prevention functions fully into play. For example, sand prevention based on landform changes, such as ditches, is a traditional method, but it is rarely used along the QTR. This is because the unique climate in the desert region of Qinghai-Tibet plateau requires unique sand solutions.

For the purpose of building an effective and scientific sand-damage–prevention engineering system along the QTR, we combined long-term observational wind data (collected by the Fenghuoshan observation station) with wind regime data (provided by the State Meteorological Administration) and field tests of various sand-prevention measures along the railway. We furthermore carried out a systematic test on the structural functions of various sand-prevention measures and their sand-control effects, which were evaluated quantitatively and semi-quantitatively. The goal was to use the results to inform the design of sand-control structures, which would in turn improve the existing sand-damage–prevention engineering systems and optimize the structural performance of various sand-damage–prevention engineering measures (Hai et al., 2007; Han et al., 2003).

2. Causes of sand damage, and structural characteristics of wind-sand flow

2.1. Causes of sand damage

In general, there are three main causes of sand damage: an arid climate, strong wind that exceeds the field threshold for sand movement, and abundant sand (Bagnold, 1941). In the Qinghai-Tibet Plateau, the average altitude exceeds 4000 m above sea level and the annual average temperature is between-3 and 7 °C, making the environment cold and arid. Under the influence of subtropical westerly winds, the Qinghai-Tibet Plateau frequently undergoes strong windy days, with speeds reaching as high as 30.2 m/s in the central Tibetan Plateau. Most sections along the QTR experience 60 of these windy days per year.

The QTR passes through many regions, such as the Hongliang River, Beilu River, Tuotuo River, Zhajiazangbu River, and Cuona Lake (Fig. 1). These regions are mostly sub-mountain, alluvial-proluvial high plains with low ground-vegetation coverage, and the earth surfaces are mainly covered by fine sand, silt, and/or silty clay, which provide abundant sand sources for the occurrence of windblown-sand damage.

A wind speed higher than that of a sand-driving wind is one of the essential conditions leading to sand damage. From the perspective of time, the occurrence of sand damage along the QTR is relatively concentrated to a couple specific times of the year. In the GoLha Section of QTR, for example, there are more than 100 strong wind days per year in areas including Wudaoliang and Amdo (with the Tuotuo River being its center). These strong wind days mainly occur in the winter and the spring. Fig. 2 shows rose diagrams of wind direction and speed in the Fenghuoshan region. The prevailing wind directions between the Xiushui River section and the Tuotuo River section are west or northwest, and are almost vertical to the trend of the railway line (Fig. 2). The majority of daily maximum-wind speeds (mean wind speed within 10 min) are higher than those of sand-driving winds(7.0 m/s; instantaneous speed; Fig. 2); therefore, this wind regime provides the necessary conditions for the occurrence of windblown-sand damage along the QTR.

2.2. Structural characteristics of wind-sand flow

The structure of wind-sand flow mainly refers to the distribution characteristics of sand grains carried by air flow along height in the carrying layer, and is one of the essential early-stage data that is analyzed to design adequate sand-damage–prevention measures. In order to effectively manage and control sand damage along the QTR, we set up windblown sand observation systems in areas where windblown-sand damages are frequently observed, so as to observe and record the spatial-movement characteristics of wind-sand flow. This would create a solid foundation for the assessment, modification, and maintenance of existing sand-damage–prevention engineering projects. These windblown sand-observation systems are mainly erected along the Hongliang River, Beilu River, and Tuotuo River sections. During the field tests we conducted, an automatic rotary

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