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Damage by wind-blown sand and its control along Qinghai-Tibet Railway in China

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ABSTRACT

Qinghai-Tibet Railway, with an average altitude of 4500 m above sea level, is the longest railway in a high altitude region. It passes through 550 km-long permafrost belt and crosses the Kunlun and Tanggulha Mountain on Tibetan Plateau. Since it opened in 2006, damage by wind-blown sand began to and rapidly spread along the railway. The aim of this paper is to provide an overview of the climatic conditions, the damage by wind-blown sand and its control along Qinghai-Tibet Railway.

1. Introduction

The Qinghai-Tibet Railway, from Xining to Lhasa, is about 1956 km long and consists of two sections, namely, XiGer Section (from Xining to Geermu) and GerLha Section (from Gerermu to Lhasa). Construction on XiGer Section began in 1979 and finished in 1984 and it is 846 km long. However, due to the harsh weather conditions and the limited railway's building technique in alpine regions, the building plan of GerLha Section was delayed. Construction began in 2001. The entire project cost about four billion dollars (US) and seven years and it was completely open to traffic in 2006. The route of Qinghai-Tibet Railway is schematically shown in Fig. 1. GerLha Section, with an average altitude of 4500 m above sea level, is the longest railway in the world in a high altitude region (Ma et al., 2005; Li, 2006; Zhu et al., 2006). It passes through 550 km-long permafrost belt, and crosses the Kunlun and Tanggulha Mountain and many deep valleys (Cheng and Wu, 2007). Moreover, the landforms along GerLha Section of Qinghai-Tibet Railway are very complex, which includes aeolian hills, mobile dunes, Gobi and alpine meadows. A typical characteristic is a unique alpine environment and strong windy condition (Wu et al., 2003; Yang et al., 2004). According to our statistics, the railway has been suffering from sand damages since 2006 and it is still spreading rapidly. In this paper, we present the existing state of wind-blown sand damage, describe the climatic condition and addressed the sand-controlling measures along the Qinghai-Tibet Railway.

2. The present status of sand damages along Qinghai-Tibet Railway

In general, the causes of sand damages include three basic factors: arid climate conditions, strong wind power and abundant sand sources. Unfortunately, all of these conditions can be met along Qinghai-Tibet Railway. Therefore, the railway is easily subjected to sand damage. According to our statistics, up to 2008, the railway affected by sand damages is about 270 km long, which accounts for one-fourth of the total length of the GerLha Section. Among which the length with severe, moderate and slight degree sand harm reached to 43, 55 and 170 km, respectively.

Damages of wind-blown sand to railways usually include two aspects in terms of its dynamic process (Johnson, 1996; Khier et al., 2000). One is the aeolian erosion and sand abrasion to railway foundations, which mainly happens in the region with strong windy conditions, bare surfaces and sparse vegetation (Copley, 1987; Bergstrom et al., 1992). Most sections along the railway are located in the center of a strong windy region on Qinghai-Tibet Plateau, generally, with more than 120 strong windy days annually. So, strong wind will provide sufficient energy for sand activities along Qinghai-Tibet Railway. And the other harm is the burial by sand, especially on roadbeds (Fig. 2a). When sand-driving wind travels through a railway's foundation, the structure of airflow around roadbed will be disturbed. Therefore, abundant sands would drop into the foundation and roadbed because wind-blown sand is blocked and deposited (Fig. 2b). The harm for this kind of wind-blown sand probably leads to some negative effects as fol-

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Fig. 1. Schematic route of Qinghai-Tibet Railway (29°06′–37°22′N, 90°05′–101°45′E).

lows. First, it will cause train to deviate away from its track if sand grains accumulate too much on the roadbed. Second, hardening of the roadbed will happen due to sand's inroads on the original gravels on the roadbed. And third, it will accelerate aeolian abrasion for railway and other instruments. For example, the damages of wind-blown sand along Tuotuohe Section mainly occurred on the upwind side of the lower reach of the river valley. The sand-attacking length exceeds 1.5 km of railway. The most serious sand-accumulated section lies between the Tuotuohe Bridge and Tanggulha Railway Station, and is about 410 m long. Patch-liked sandy sediment frequently does harm to the foot of the roadbed, commonly with a width of about 3 m and thickness of 20 cm.

3. The causes of sand damages

Generally, the causes of sand damages could be divided into two kinds, climate factors and human activity. Located in the westerlies belt, the wind in the Tibet Plateau is strong, especially in spring and winter. This supplies the driving force for sand damage. In another hand, it is well known that the Tibet Plateau is an environmentally fragile area. According to previous studies, the Tibet Plateau is also one of the most sensitive regions to global climate change. Global warming will accelerate permafrost degradation and land desertification, leading to accelerated sand damage.

Strong winds (>17 m s^{-1}) are common in many sites along Qinghai-Tibet Railway and annual mean strong windy days may reach in excess of 60 because of the effect of cold fronts around Qaidam Basin and the subtropical westerlies. For example, the windy days in Tuotuohe River, Anduo and Wudaoliang reaches 168, 148 and 136 in a year respectively. The peak of wind speed usually exceeds 25 m s^{-1}, even get to 38 m s^{-1} in Anduo (Bai et al., 2005). Moreover, there is less than 100 cm rainfall annually in the north regions of Tibet Plateau, which mainly occurs during summer. In contrast, precipitation is very scarce in winter when strong wind is common. Therefore, wind-blown sand activities occur frequently and last for long time with high-energy, which threaten the safe operation of trains. Fig. 3 shows the relationship between monthly wind speed and precipitation in Tuotuohe Station. It can be seem that windy periods occur with droughty climate.

Drift potential (DP) measures the energy of surface winds in terms of sand movement (Fryberger and Dean, 1979). The direction and magnitude of vector resultants of drift potential from the 16 compass directions are herein known as the resultant drift direction (RDD) and the resultant drift potential (RDP), respectively. An index of the directional variability of the wind is the ratio of the resultant drift potential to the drift potential, herein known as RDP/DP. The greater the directional variability of the

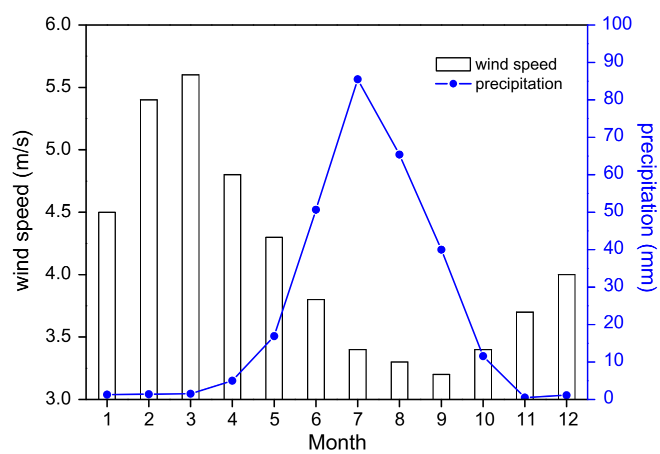

Fig. 3. Monthly mean wind speed and precipitation in Tuotuohe station along Qinghai-Tibet Railway.

a. Zhajiangzangbu (taken on August 2006) b. Xiushuihe River (taken on January 2008)

Fig. 2. The harm of wind-blown sand along Qinghai-Tibet Railway.

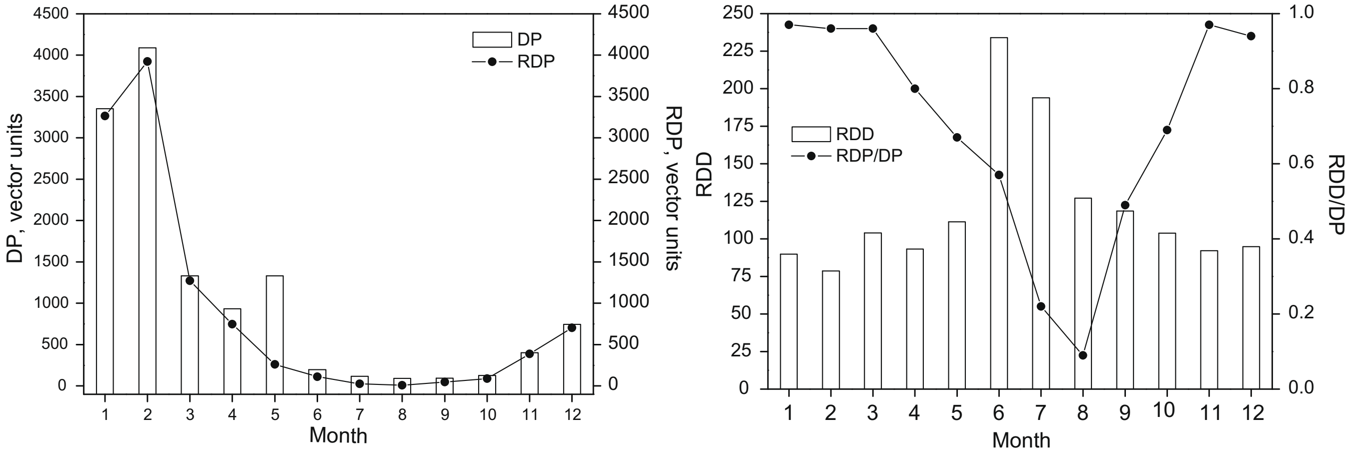

Fig. 4. Sand-drift parameters in different months in Wudaoliang station (DP is drift potential, RDP is resultant drift potential).

effective winds at a station, the lower its associated RDP/DP will be.

Fig. 4 shows drift potential, resultant drift potential and directional ratio monthly in Wudaoliang Station along Qinghai-Tibet Railway. Drift potential is higher in winter-spring period, especially in February it reaches the peak value of 4090.1 vector units (VU). And then it decreases and keeps low until August with the lowest value of 92.04 VU. The correlation between drift potential and resultant drift potential is distinct, which reflects wind regime with a singular direction and long duration. Resultant sand-drift direction is northwesterly from October to April and directional ratio is more than 0.8 in this period. While in August, the directional ratio reaches to the lowest value of 0.22 in a year, which indicates multi-directional wind in this period.

4. Sand-control measures and their function along Qinghai-Tibet Railway

In order to protect the roadbed from attack by wind-blown sand, many measures have been adopted along Qinghai-Tibet Railway since the beginning of railway construction. However, up to now, only four measures have proved effective for sand control and which have been used along entire Qinghai-Tibet Railway. Classified by the function of sand-control measures, they include sand-fixing barrier,

a. Rocky checkerboard sand barrier
b. Sand-blocking fence
c. Sand-deviating board
d. Wind-weaken leaf

Fig. 5. Sand-control measures along Qinghai-Tibet Railway.

sand-blocking fence, sand-deviating board and wind-weaken leaf. Rocky checkerboard sand barrier (Fig. 5a) is derived from the straw checkerboard sand barrier, which is effective for fixing mobile sand in arid and semi-arid regions. Being in a high-energy wind environment along Qinghai-Tibet Railway, the materials used for sand control were changed from traditional straw and reed to rock and concrete. The rocky checkerboard sand barrier is mainly used to fix mobile sand far from the railway. Sand-blocking fences, having a given porosity pattern determined by the local wind regime, is used at a distance from railway to control distant sand sources and block sand flow (Fig. 5b). Sand-deviating boards alter the direction of sand flow and let it flow away from railway instruments (Fig. 5c). The last measure for sand-control is the wind-weaken leaf with many pieces of leaf-shaped concrete, and it can effectively decrease wind speed near the railway (Fig. 5d).

It is well-known that much progress has been made in aeolian sand control in arid and semi-arid regions of China (Wang et al., 2006). However, work on Tibet Plateau is new. Due to low air pressure and air density, the characteristics of wind-blown sand in alpine regions are different from that of arid and semi-arid regions at lower elevations. Correspondingly, this will certainly lead to differences in sand-controlling measures. Unfortunately, at the beginning of the railway construction, no existing sand-controlling measures had been developed specifically for alpine regions. Therefore, some measures used for arid and semi-arid regions temporarily have been adopted along the railway. In order to control sand damage effectively and scientifically, research is needed on the differences in sand grain movement between alpine regions and arid and semi-arid lands.

5. Discussion and conclusions

Located in Tibet Plateau, the Qinghai-Tibet Railway is destined to suffer from damage by wind-blown sand. With the climate changing and human activities increasing, sand damage along the railway will increase in the future. Although many sand-control measures were adopted, the harm of wind-blown sand is still very serious. The main reasons are indicated from two points. Firstly, sand damage is more serious than originally anticipated and is increasing gradually, which increases the difficulty of controlling wind-blown sand. Secondly, Qinghai-Tibet Railway lies in a unique high elevation region where air density and air pressure is different from that in inland sandy areas. For example, the altitude of the Tanggulha Railway Station is 5068 m and the air pressure is only about 52% of sea-level pressure. The drag velocity is related to the shear stress exerted by the wind on the bed and to the density of air (McKenna-Neuman, 2003). The threshold velocity is also dependent on the density of air (Pye, 1987). In addition, wind tunnel simulations of aeolian transport showed that cold airflows support higher mass transport rates than warm air (McKenna-Neuman, 2004). Therefore, the drag velocity, threshold velocity and sand transport are different along Qinghai-Tibet Railway, which adds complexity for clarifying the dynamical mechanism of wind-blown sand activities on high-cooling region. In a word, how to control sand damages effectively and scientifically along Qinghai-Tibet Railway has become a new challenge both for government and scientists.

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