Wind Characteristic Analysis of 100-Kilometer Wind Area in Lanzhou-Xinjiang High-Speed Railway

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ABSTRACT

The wind speed data collected by 49 disaster prevention and mitigation system monitoring stations in 100-Kilometer Wind Area in Lanzhou-Xinjiang High-Speed Railway were adopted as sample data, and the temporal-spatial characteristics of strong wind in 100-Kilometer Wind Area in year 2015 were analyzed by extreme wind speed temporal-spatial statistics method, time distribution statistics method of strong wind and wind rose diagrams. The analysis result indicates that the 100-Kilometer Wind Area is characteristic of high wind speed, long wind period and stable wind direction. The distribution of strong wind in 100-Kilometer Wind Area possesses obvious regional distribution characteristic. Specifically, the extreme wind speed within the area can reach 40.1m/s at highest, and the locations with an extreme wind speed higher than 35m/s are mainly distributed between mileage K2982 and K3033. Besides, the extreme wind speed reduces from the middle to both east and west sides. The number of strong wind days in 2015 is 216, the number of strong wind days with a wind speed ≥24.5 m/s is 121 and the number of strong wind days with a wind speed ≥32.7 m/s is 32, thus the wind period is long. The dominant wind direction at each wind speed monitoring station is mainly centered between NNE and NNW, and the wind is mainly demonstrated as transverse wind perpendicular to the line direction, and the wind direction is stable.

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1. INTRODUCTION

Lanzhou-Xinjiang High-Speed Railway passes through 4 Wind Areas alongside the Gobi in front of the southern foothill of Mountain Tianshan. The length of the line in strong wind area reaches 462.41km and accounts for 65% of the total length of the railway line in Xinjiang (see Figure 1). The 100-Kilometer Wind Area located between Xiaocaohu and Liaodun Station is the core of Lanzhou-Xinjiang High-Speed Railway among the strong wind areas[1-2]. This wind area is dominated by typical gobi and desert landform, with special geological location and climate, characteristic of terrible natural conditions[3]. The particularity of geological location and climate leads to an easy way to form strong wind[4]. With frequent occurrences, strong wind in this wind area causes many bad influences on the operation safety of Lanzhou-Xinjiang High-Speed Railway Line.

Figure 1. Schematic for wind area distribution of Lanzhou-Xinjiang High-Speed Railway Line.

Strong wind disaster is one of the most critical issues influencing the operation safety of Lanzhou-Xinjiang High-Speed Railway while the instantaneous wind speed and prevailing wind direction are the major factors influencing the operation safety of trains traveling on the high-speed railway line[5]. Therefore, utilizing measured climate data to study the strong wind characteristics in 100-Kilometer Wind Area, which is considered the core of the strong wind areas alongside Lanzhou-Xinjiang High-Speed Railway Line, and grasping the temporal-spatial distribution characteristics of extreme wind speed and number of strong wind days in this area as well as the change rule of wind direction can provide scientific basis for operation
safety and administrative decision-making of Lanzhou-Xinjiang High-Speed Railway and be of positive practical significance to guarantee the operation safety of EMUs units under strong wind weather.

2. RESEARCH METHOD

2.1 Data Source

To prevent the risks and avoid influences of natural disasters (the wind, rain, snow, earthquake etc.) on the operation safety of Lanzhou-Xinjiang High-Speed Railway Line, a natural disaster and foreign matter invasion limit monitoring system (see Figure 2), shortened as disaster prevention and mitigation system, is set up alongside the line.

The wind monitoring station adopts the WS500-UMB ultrasonic wind speed and direction indicator (regular type) provided by Lufft Corp. and Ventus-V200A ultrasonic wind speed and direction indicator (enhanced type) as the double backup wind speed sensors. The monitoring data of both two sensors are stored inside the database. The data from one channel are referred to by the wind speed sub-system in high-speed railway disaster prevention system and are displayed on the control console. The referred data are judged by the software independently. When the data from one channel fail, the system automatically switches to the other data channel and refers to the data.

Figure 2. Schematic for disaster prevention and reduction system in Lanzhou-Xinjiang High-Speed Railway Line.
Since the end of 2014 when the Lanzhou-Xinjiang High-Speed Railway in Xinjiang started operating, 158 wind monitoring stations have been set up alongside the railway line. Specifically, 51 stations are set up in 100-Kilometer Wind Area (K2954+225–K3124+139). In this paper, the strong wind monitoring data in the typical 100-Kilometer Wind Area are used as analysis object in order to study the distribution characteristics of average wind speed, extreme wind speed and wind direction angle at each wind monitoring station.

2.2 Analysis Method

2.2.1 EXTREME WIND SPEED DISTRIBUTION

The equipment in wind monitoring stations set up in 100-Kilometer Wind Area is mainly Ventus-V200A detector, the sampling frequency of which is 4Hz. Different from the 3-second instantaneous wind speed, 2-minute average wind speed and 10-minute average wind speed focused on by meteorological departments, the wind speed data transmitted from the railway line disaster prevention and reduction system to control console include the 1-second instantaneous wind speed by adopting the average of 4 wind speed data in 1 second. It focuses on the instantaneous wind speed which has a larger influence on operation safety.

When the time step of wind direction and speed is 1 second, and the 1 minute and 2 minutes sliding averages are calculated. When the time step is 1 minute, the 10 minutes sliding average is calculated. The calculation formula is:

\[
\bar{A}_n = \frac{(\alpha_n - \bar{A}_{n-1})}{N_0} + \bar{A}_{n-1}
\]

(1)

Where, \(\bar{A}_n\) is the average of \(nth\) sample. \(\bar{A}_{n-1}\) is the average of the \((n-1)th\) sample. \(\alpha_n\) is the \(nth\) wind speed sample. \(N_0\) is the number of samples in the range. During processing of 1-second instantaneous wind speed, \(N_0=4\).

The 1-second average processed instantaneous, 2-minute average and maximum wind speed, and 10-minute average and maximum wind speed are collected to obtain the temporal-spatial distribution characteristics of strong wind in wind areas of Xinjiang railway.

2.2.2 FREQUENCY STATISTICS OF WIND DIRECTION ANGLE

The monitoring data of wind direction angle ranges between 0° and 360°. The zero-crossing processing calculation formula is:
The discrete wind direction angle data measured by wind monitoring station is \( \alpha_i \) \((i=1\sim N, N \text{ is the number of sample data})\). The maximum and minimum wind direction angles are respectively \( \alpha_{Tm} \) and \( \alpha_{T0} \), the number of groups is \( m \), and the group interval \( T \) is:

\[
T = \frac{\alpha_{Tm} - \alpha_{T0}}{m}
\]

The internal of wind direction angle group \( \alpha_{Tj} \) is:

\[
\alpha_{Tj} = \alpha_{T0} + j \cdot T (j = 1 \sim m)
\]

The data frequencies of wind direction angles in different groups are collected as:

\[
F_j = \sum_{i=1}^{N} f(\alpha_i)(i = 1 \sim N, j = 1 \sim m)
\]

Where, \( f(\alpha_i) \) is the function judging whether the sample wind direction angle data lie within the wind direction angle range.

\[
f(\alpha_i) = \begin{cases} 
1, & \alpha_{T(j-1)} \leq \alpha_i < \alpha_{Tj} \quad (i = 1 \sim N, j = 1 \sim m) \\
0, & \text{else}
\end{cases}
\]

Thus, the prevailing wind direction statistical figure of different wind direction angles can be obtained.

3. WIND CHARACTERISTIC ANALYSIS OF 100-KILOMETER WIND AREA IN LANZHOU-XINJIANG HIGH-SPEED RAILWAY LINE

3.1 Spatial Distribution Characteristics of Wind Speed

From the distribution line chart of the instantaneous maximum wind speed in 100-Kilometer Wind Area (see Figure 3), the instantaneous maximum wind speed in the wind area can reach 40.1m/s at highest. In addition, the extreme instantaneous wind speed values are distributed between Liaodunbei (K2999+489) and Hongcengnan (K3044+139), and then reduces towards both east and west sides. The wind force reduces from the center core area towards both edges in the wind area.
3.2 Temporal Distribution Characteristics of Wind Speed

3.2.1 MONTHLY WIND DISTRIBUTION CHARACTERISTICS OF A NATURAL YEAR

The maximums of monthly instantaneous maximum wind speed in 100-Kilometer Wind Area in Lanzhou-Xinjiang High-Speed Railway in 2015 are adopted to obtain the distribution curve of maximum monthly instantaneous wind speed (see Figure 4). We can conclude that:

1) The maximum monthly wind speed in 100-Kilometer Wind Area occurs in spring. The reason is that the temperature increases quickly during spring and the activity of cold air is frequent, easily leading to high air pressure difference. In addition, the shortage of coverage on ground surface, low roughness and small resistance easily lead to form strong wind.

2) From August to November, 100-Kilometer Wind Area enters into the second strong wind frequent season and the instantaneous maximum wind speed is above 35m/s. Considering that the strong wind in 100-Kilometer Wind Area are strong, the maximum wind speed in all the months except January is above 32.7m/s.
3.2.2 DISTRIBUTION CHARACTERISTICS OF STRONG WIND DAYS OF NATURAL YEAR AND MONTH

According to the regulation in Specifications for Surface Meteorological Observation[6], the wind with an instantaneous wind speed equal to or higher than 17.0 m/s is defined as strong wind. Considering the day in which strong wind is recorded, no matter how many strong wind occur in that day, this day is calculated as one strong wind day. Thus, the strong wind data in 100-Kilometer Wind Area in 2015 are sorted out to obtain the number of monthly and annual strong wind days with a wind speed equal to or higher than 17.0 m/s, 24.5 m/s and 32.7 m/s at each monitoring station in 100-Kilometer Wind Area (see Figure 5).

It can be known from the analysis result that:

1) In 2015, the number of strong wind days in 100-Kilometer Wind Area is 216. The number wind days with a wind speed $\geq 24.5$ m/s in the whole year is
121 and the number wind days with a wind speed \( \geq 32.7 \text{m/s} \) in the whole year is 32. This complies with the actual operation condition of current Lanzhou-Xinjiang High-Speed Railway Line, and impact from strong wind on EMUs is the greatest in 100-Kilometer Wind Area.

2) Fig. 5 shows the monthly change of strong wind days in 100-Kilometer Wind Area: the months with a larger number of strong wind days are basically concentrated between March and October. The strong wind with a wind speed \( \geq 24.5 \text{ m/s} \) are distributed in each month and basically concentrated between March and September. The strong wind with a wind speed \( \geq 32.7 \text{ m/s} \) are distributed in each month except January.

### 3.3 Statistical Frequency Characteristics of Prevailing Wind Directions

The wind monitoring data between the 11th (K3005+268) and 41st monitoring station (K3081+839) which have larger instantaneous maximum wind speeds in 100-Kilometer Wind Area are applied in the frequency statistics of prevailing wind directions. According the frequency calculation formula (5) of wind direction angle, the prevailing and secondary prevailing wind directions and frequencies at major monitoring stations are shown in Table I.

<table>
<thead>
<tr>
<th>Monitoring station mileage</th>
<th>Prevailing wind direction</th>
<th>Frequency</th>
<th>Secondary prevailing wind direction</th>
<th>Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>K3005+268</td>
<td>NNW</td>
<td>79%</td>
<td>NW</td>
<td>19%</td>
</tr>
<tr>
<td>K3018+846</td>
<td>NNW</td>
<td>86%</td>
<td>NW</td>
<td>8%</td>
</tr>
<tr>
<td>K3028+438</td>
<td>N</td>
<td>65%</td>
<td>NNE</td>
<td>34%</td>
</tr>
<tr>
<td>K3038+414</td>
<td>NNW</td>
<td>76%</td>
<td>N</td>
<td>17%</td>
</tr>
<tr>
<td>K3051+009</td>
<td>NNE</td>
<td>84%</td>
<td>NE</td>
<td>14%</td>
</tr>
<tr>
<td>K3064+821</td>
<td>NNE</td>
<td>43%</td>
<td>NNW</td>
<td>31%</td>
</tr>
<tr>
<td>K3074+739</td>
<td>NNW</td>
<td>51%</td>
<td>N</td>
<td>39%</td>
</tr>
<tr>
<td>K3087+839</td>
<td>WNW</td>
<td>73%</td>
<td>NW</td>
<td>27%</td>
</tr>
</tbody>
</table>

It can be known from the statistical result of prevailing wind direction at typical wind monitoring stations in 100-Kilometer Wind Area that:

1) The prevailing wind direction for strong wind with a wind speed \( \geq 20 \text{ m/s} \) in 100-Kilometer Wind Area of Lanzhou-Xinjiang High-Speed Railway is stable and mainly concentrated between NNE and NNW direction.

2) In the K3005~K3028 mileage range in which the instantaneous maximum wind speed is higher, the prevailing wind direction for strong wind mainly
concentrated between NNW and N direction, and the secondary prevailing wind
direction is concentrated between NW and N direction.

(3) Normally, when the railway line is perpendicular to the wind direction
angle, the high-speed trains operating on this line will be influenced by transverse
wind and the hazard to safe train operation is the highest.

The principle that the railway line should cross the strong wind straightly is
adopted during the design of Lanzhou-Xinjiang High-Speed Railway in order to
pass through the strong wind areas at the shortest distance and reduce the influence
of strong wind. Thus, the railway line in 100-Kilometer Wind Area is parallel
paved at the downstream wind gap and basically perpendicular to the wind
gap[7-8]. In combination of the analysis result on prevailing wind direction in
100-Kilometer Wind Area, it can be assumed that the railway line in
100-Kilometer Wind Area of Lanzhou-Xinjiang High-Speed Railway is mainly
influenced by strong transverse winds and the impact on operation safety of EMUs
is the greatest.

4. CONCLUSIONS

(1) The instantaneous maximum wind speed in 100-Kilometer Wind Area in
Lanzhou-Xinjiang High-Speed Railway can reach 40.1 m/s at highest, and the
extreme instantaneous wind speed values are distributed between Liaodunbei
(K2999+489) and Hongcengnan (K3044+139), and then reduce towards both east
and west sides.

(2) The maximum monthly wind speed of 100-Kilometer Wind Area occurs
in the spring. The strong wind are the second most frequent from August to
November.

(3) In 2015, the number of strong wind days in 100-Kilometer Wind Area is
216. The number wind days with a wind speed \( \geq 24.5 \) m/s in the whole year is
121 and the number wind days with a wind speed \( \geq 32.7 \) m/s in the whole year is
32. The months with a larger number of strong wind days are basically
concentrated between March and October. the strong wind with a wind speed \( \geq 24.5 \) m/s are distributed in each month and basically concentrated between March
and September. the strong wind with a wind speed \( \geq 32.7 \) m/s are distributed in
each month except January.

(4) The prevailing wind direction for strong wind with a wind speed \( \geq 20 \)
m/s in 100-Kilometer Wind Area of Lanzhou-Xinjiang High-Speed Railway is
stable and mainly concentrated between NNE and NNW direction. In the
K3005~K3028 range in which the instantaneous maximum wind speed is higher, the prevailing wind direction for strong wind mainly concentrated between NNW and N direction, and the secondary prevailing wind direction is concentrated between NW and N direction. The railway line in 100-Kilometer Wind Area is mainly affected by strong transverse winds.

(5) Considering the limit to the data sample collected in this study, only an initial analysis is carried out on the strong wind characteristics of 100-Kilometer Wind Area in Lanzhou-Xinjiang High-Speed Railway Line. In the future, as the data samples keep accumulating, a further deeper investigation can be carried out on the annual change rules of strong wind characteristics and evolutionary trends of extreme strong wind climates of 100-Kilometer Wind Area in Lanzhou-Xinjiang High-Speed Railway Line.

REFERENCES