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An Evaluation of Wind Increments for Optimizing Operation Control Under Strong Wind in Railways

K. Araki, K. Takami, T. Fukuhara and S. Tanimoto

Meteorological Disaster Prevention, Disaster Prevention Technology Division
Railway Technical Research Institute, Kokubunji, Tokyo, 185-8540, Japan

Abstract

In order to optimize operation control under strong wind in railways, we analysed increments in wind speeds in windy events observed by 205 anemometers over 51months. First, we calculated 205 relative frequencies F of 1-minute maximum instantaneous wind speeds of 25m/s or more, and we classified F into five groups based on the average μ_F and the standard deviation σ_F of the relative frequencies F. Next, we analysed increments in wind speed δ_t by using 3,947 windy events which consist of time series of the wind speed including 1-minute maximum instantaneous wind speeds of 25m/s or more. As a result, it was clear that the increments in wind speed of the same evaluation time t differ by five groups classified by μ_F and σ_F. Therefore, appropriate wind speed for operation control can be established with consideration of the increments in wind speed δ_t according to the relative frequencies F.

Introduction

To prevent wind-induced train accidents, Japanese railway companies are taking countermeasures such as establishing train operation control under strong winds and installing windbreak fences. Train operation control makes sure that a train won't be exposed to dangerous strong wind. When wind speeds which were observed by anemometers installed in train operation control sections exceeded the wind speeds for operation control, train dispatchers instruct drivers to decelerate or stop the train. The wind speeds for operation control are established based on the critical wind speed for overturning (CWS), and instantaneous wind speed of 25m/s or 30m/s are often adopted in Japan. With regard to the CWS, internationally, studies on the problem of crosswinds, such as the AOA DEUFRAKO project, have clarified that high-speed trains are sensitive to crosswind [1-3]. On the other hand, in Japan, Hibino et al. proposed “the detailed equation” for calculation of the CWS and verified its validity [4-5]. The CWS calculated by “the detailed equation” differs according to the vehicle shape, cross-sectional shapes of railway structures, and angles between the travelling directions of the train and wind directions. The wind speeds for operation control are established lower than the CWS. At the same time, it's desirable to consider wind characteristics which blow into train operation control sections. Natural winds fluctuate spatially and temporally. Therefore a possibility that a train which running in a train operation control section is exposed to strong wind beyond the wind speeds for operation control won't be zero. The most pessimistic scenario is the case that a running train in a train operation control section is exposed to strong wind beyond its CWS. For the purpose of establishing the wind speeds for operation control which can prevent this pessimistic scenario and to optimize operation control under strong wind in railways, this paper reports the wind characteristics, especially increments in wind speeds, by using the windy data observed by 205 anemometers.

Research Methodology

Observational wind data used for analysis

We analysed the wind characteristics by using the observational wind speed data obtained at 205 cup anemometers installed along railway lines in west Japan from April 2012 to June 2016. Raw data of wind speed obtained at 2 second intervals. Here, we can't obtain data of wind direction because 205 anemometers are type of cup, not type of propeller-vane. In this study, we analysed the wind characteristics by using data set of 1-minute maximum instantaneous wind speeds calculated from raw data of wind speed obtained at each anemometer.

Classification of the frequency of strong wind

First, we calculated relative frequencies F of 1-minute maximum instantaneous wind speeds of 25m/s or more at each anemometer over 51 months. Here, relative frequency F means the number of 1-minute maximum wind speeds exceeding the threshold divided by the number of valid 1-minute maximum wind speeds. We adopted instantaneous wind speed of 25m/s as the threshold. It is because that the value of 25m/s is often adopted as the wind speed for operation control in Japan. Next, to classify windy points in west Japan, we calculated the average and the standard deviation from the relative frequencies of 1-minute maximum instantaneous wind speeds of 25m/s or more obtained at 205 anemometers. And we analysed increasing tendency and recovery tendency of wind speeds at each classified point.

Analysis of the increment in wind speeds in windy events

To analyse the increment in wind speeds, we extracted windy events from data set of 1-minute maximum instantaneous wind speeds at 205 anemometers. Windy events consist of time series of the wind speed including 1-minute maximum instantaneous wind speeds of 25m/s or more (figure 1). Here, to extract windy events, the following assumptions were made with regard to the wind monitoring method and the train operation control method for a train operation control section.

- One anemometer is installed in the windiest point in one train operation control section.
- The wind observed by the anemometer is blowing uniformly in the whole train operation control section.
- A train can enter a train operation control section when the instantaneous wind speed continues less than 25m/s for more than 15 minutes.

- After a train entered a train operation control section, when an anemometer observes instantaneous wind speeds of 25m/s or more, train operation is suspended.
- Operation control is resumed when the instantaneous wind speed continues less than 25m/s for more than 15 minutes.

Finally, we obtained 3,947 windy events from data set of 1-minute maximum instantaneous wind speeds at 152 anemometers. We defined the increment in wind speed δ_t as the difference between the wind velocity at the base time t_0 and the maximum wind speed in the subsequent t minutes after the base time t_0 (figure 2). The base time t_0 means the first time when instantaneous wind speeds exceeded 25m/s or more in each windy event. We calculated δ_t from 3,947 windy events. Values of t ranged from 5 minutes to 60 minutes at intervals of 5 minutes.

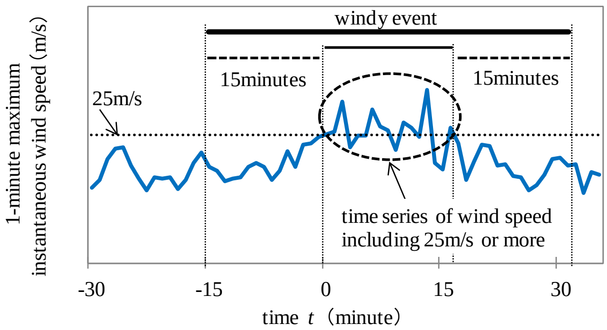

Figure 1. Conceptual diagram of windy event

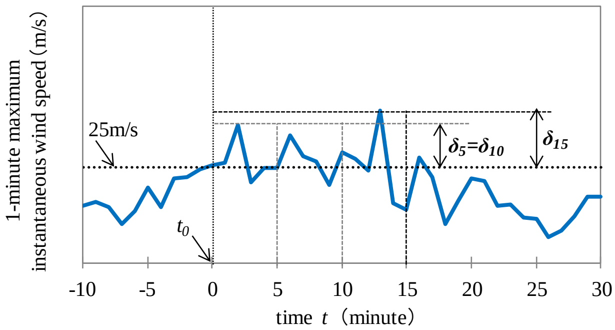

Figure 2. Conceptual diagram of the increment in wind speeds δ_t

Results

Relative frequencies of strong wind and its classification

We calculated relative frequencies F of 1-minute maximum instantaneous wind speeds of 25m/s or more observed by 205 anemometers over 51 months. As a result, 1-minute maximum instantaneous wind speeds of 25m/s or more were obtained at 152 anemometers out of 205 anemometers. The average μ_F and the standard deviation σ_F of relative frequencies F were 0.036 and 0.073, respectively. We classified F into five categories based on μ_F and σ_F as shown in table 1 and figure 3. Group 1 included twelve anemometers and were highly recommended establishment of countermeasures against strong wind. Also group 2, 3, 4 and 5 included 6, 12, 21 and 101 anemometers, respectively. Railway companies checked to see if our classification was right. As it turned out that windbreak fences were installed already in about 80% of operation control sections where anemometers which belong to group 1 were installed. Also, windbreak fence was installed already in one operation control section where anemometers which belong to group 2 were installed. These results validated our classification by using μ_F and σ_F. This classification method can be utilized for the assessment for the priority of countermeasures against strong wind.

Group	Range of F	
1	$\mu_F + 2\sigma_F \leqq F$	$0.18 \leqq F$
2	$\mu_F + 1\sigma_F < F \leqq \mu_F + 2\sigma_F$	$0.11 < F \leqq 0.18$
3	$\mu_F + 0.5\sigma_F < F \leqq \mu_F + 1\sigma_F$	$0.072 < F \leqq 0.11$
4	$\mu_F < F \leqq \mu_F + 0.5\sigma_F$	$0.036 < F \leqq 0.072$
5	$F \leqq \mu_F$	$F \leqq 0.036$

Table 1. Classification of relative frequencies F

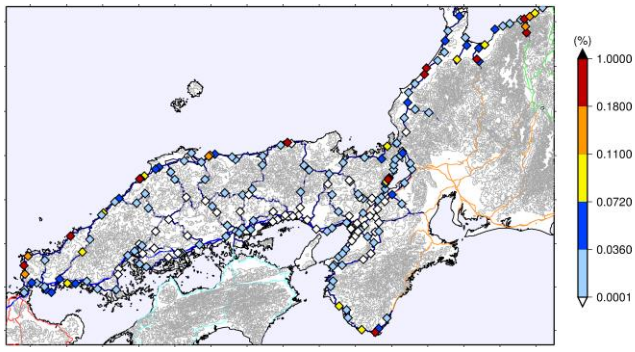

Figure 3. Distribution of relative frequencies of 1-mimute maximum instantaneous wind speed of 25m/s or more

Increments in wind speeds in windy events

We calculated the increments in wind speed δ_t from 3,947 windy events obtained by 152 anemometers. According to the classification of relative frequencies F shown in figure 3, 3,947 windy events were also classified into five groups. The number of windy events from group 1 to 5 was 1,645, 455, 563, 568 and 718, respectively. Figure 4 shows the non-exceedance rates of increment in wind speed δ_t in case of t = 5, 10, 20, 40. As the tendency common to all groups, it was confirmed that as the evaluation time t became long, larger increments in wind speed occurred. On the other hand, comparison of the increments in wind speed of the same evaluation time t between different groups indicated that the larger the relative frequencies F, the larger the increments in wind speed δ_t. For example, the profile of the increment in wind speed δ_5 in group 1 was almost the same as the profile of the increment in wind speed δ_{10} in group 4 or 5. Therefore, appropriate wind speed for operation control can be set with consideration of the increments in wind speed δ_t according to the relative frequencies F. Here, we investigated the weather turbulences which trigger the increments in wind speed δ_t in 3,947 windy events. Figure 5 shows the relative frequencies of weather turbulences which trigger windy events at each group. The sum of the relative frequencies of front and wintery pressure accounted for 40 to 50% of the whole by all groups excepting group 5. The relative frequencies of low pressure were less than 10 % of the whole by all groups. On the other hand, the relative frequencies of typhoon became larger with the decrease of the relative frequencies F. Generally, the wind speed generated by the typhoon is larger than the wind speeds generated by other weather turbulences. However, the landfall frequencies of the typhoon and their passage course vary from year to year. Therefore, it is suggested that the occurrences of windy events at the points classified into group 1 and 2 highly depended on the weather turbulences which occur throughout the year such as front, high and low pressure. But the occurrences of windy events at the points classified into group 4 and 5 depended on the typhoon rather than the weather turbulences which occur throughout the year.

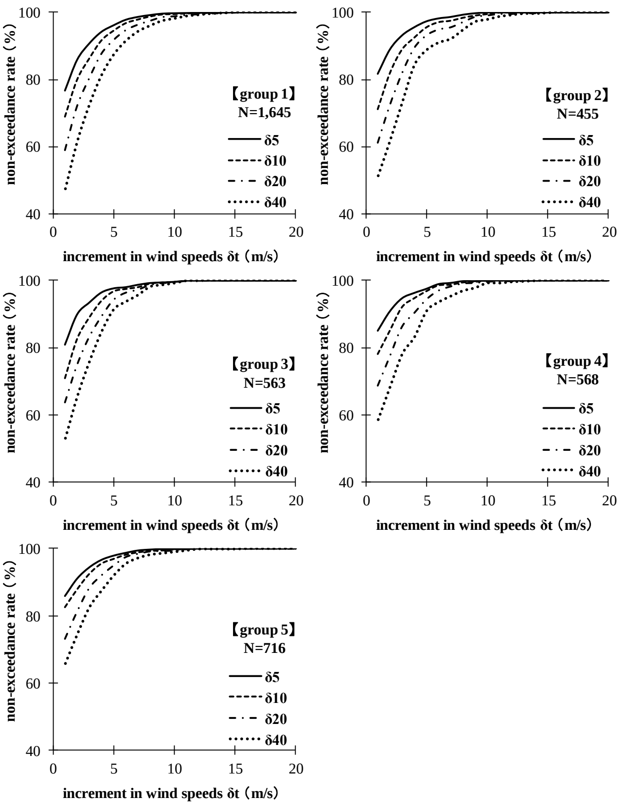

Figure 4. Non- exceedance rates of increment in wind speed δ_t

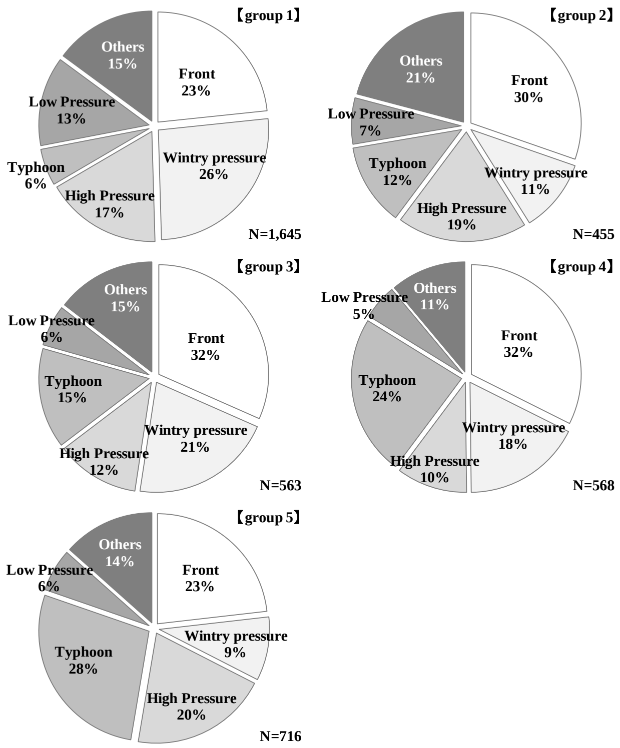

Figure 5. Relative frequencies of whether turbulences which trigger windy events

Conclusions

In order to optimize operation control under strong wind in railways, we analysed increments in wind speeds in windy events by using the windy data observed by anemometers over 51months. The following findings were obtained.

- We calculated relative frequencies F of 1-minute maximum instantaneous wind speeds of 25m/s or more observed by 205 anemometers over 51 months. We classified F into five groups based on the average μ_F and the standard deviation σ_F of the relative frequencies F, and validated our classification.
- It is clear that the increments in wind speed of the same evaluation time t differ by five groups classified by μ_F and σ_F. Therefore, appropriate wind speed for operation control can be established with consideration of the increments in wind speed δ_t according to the relative frequencies F.
- It is suggested that the occurrences of windy events at the points classified into group with high frequencies F highly depended on the weather turbulences which occur throughout the year such as front, high and low pressure. On the other hand, the occurrences of windy events at the points classified into group with low frequencies F depended on the typhoon rather than the weather turbulences which occur throughout the year.

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