A wind prediction method for the train operation based on the onsite measurement and the numerical simulation

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ABSTRACT

In this study, wind prediction method for the train operation based on the onsite measurement and the numerical simulation. Figure 1 shows the flow of the method. First, from one year simulation by mesoscale model and microscale model, the wind speed ratio and the change in wind direction between the site of interest and the measurement site are calculated. Then, from the wind speed ratio, the change in the wind direction and the measured wind speed, the mean wind speed at any point can be predicted. Finally, based on the turbulence intensity estimated from the numerical simulation, gust factor is calculated to estimate the maximum wind speed.

This method was applied to the estimation of frequency of wind speed over 25m/s at the measurement site and compared with the measurement. Proposed method shows good agreement with the measurement while conventional methods, which assumes complete correlation or ignores the correlation of wind speed between two points along the railway, overestimates or underestimates the frequency of occurrence of wind speed over 25m/s(Fig.2).

INTRODUCTION

Railway operators regulate the train operation or settle the wind fence as countermeasures of the strong wind. Current regulation based on a on site measurement of the wind speed cannot detect strong wind at the other sites although it can catch all the strong wind event at the measurement site. On the other hand, recent development of the numerical prediction of wind by mesoscale meteorological model and microscale model enables the predictions of special distribution of the wind speed and the annual frequency distribution of wind speed. But the numerical prediction has a limitation that it cannot predict all the strong events.

In this study, a new wind prediction method was proposed by considering the advantage of the onsite measurement and the numerical simulation. Then based on the proposed method, time series of the wind speed and the frequency of the strong wind event were investigated quantitatively.

A NEW METHOD FOR THE PREDICTION OF THE WIND ALONG RAILWAY

The flow of the proposed method is shown in figure 1. First, using the results of one year simulation of mesoscale meteorological model and microscale wind prediction model, wind speed ratio between the prediction sites and the measurement site is calculated. Then, from the 10 minutes averaged wind speed at the measurement site and the calculated wind speed ratio, 10minutes averaged wind speeds at the predictions sites are predicted. Next, from the estimated turbulence intensity by the numerical simulation, gust factor for each wind direction is calculated and the maximum gust is estimated at the prediction sites. In this section, the concrete method to calculate the 10minuets averaged wind speed and maximum gust is described.

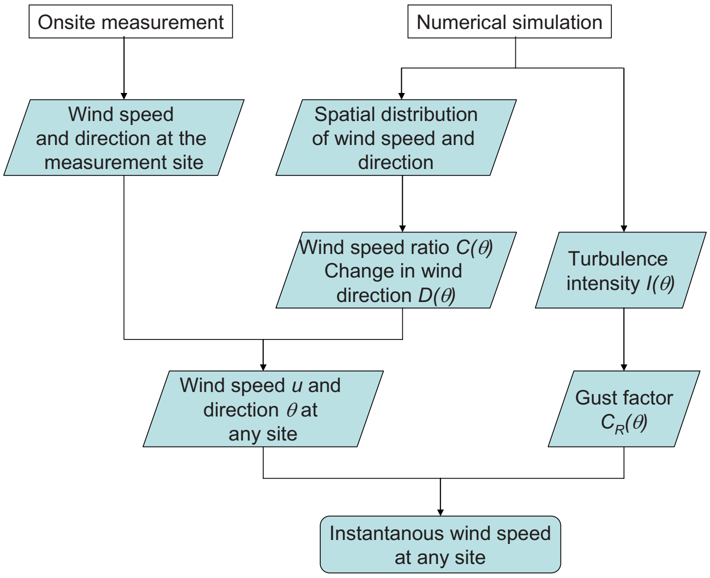

Fig. 1 The flow of the wind prediction using onsite measurement and numerical simulation

Prediction of mean wind speed and direction

From the numerical simulation using mesoscale and microscale model, time series of the wind velocity for one year can be calculated. In this study, the wind speed ratio and the change in the wind direction are assumed to be the function of only wind direction and the ratio and the change in the wind direction are estimated using least square method. As a mesoscale and microscale model, RAMS (Pielke et al., 1992) and MASCOT (Ishihara et al., 2003) were used respectively.

Let the wind speed and direction calculated by the numerical simulation $u_{\mathrm{ref}}^{\mathrm{model}}(t)$ and $\theta_{\mathrm{ref}}^{\mathrm{model}}(t)$, respectively and let the wind speed and the direction at the prediction site $u_{\mathrm{site}}^{\mathrm{model}}(t)$, $\theta_{\mathrm{site}}^{\mathrm{model}}(t)$, respectively. The wind speed ratio $C(\theta_{\mathrm{ref}}^{\mathrm{model}})$ and the change in wind direction $D(\theta_{\mathrm{ref}}^{\mathrm{model}})$ between the two sites is estimated as functions of the wind direction by the numerical simulation $\theta_{\mathrm{ref}}^{\mathrm{model}}$ by least square method so that the errors shown in equation (1) and (2) are minimized.

$$\sum_t \left(u_{\mathrm{ref}}^{\mathrm{model}}(t) \times C(\theta_{\mathrm{ref}}^{\mathrm{model}}) - u_{\mathrm{site}}^{\mathrm{model}}(t)\right)^2 \qquad (1)$$

$$\sum_t \left(\theta_{\mathrm{ref}}^{\mathrm{model}}(t) + D(\theta_{\mathrm{ref}}^{\mathrm{model}}) - u_{\mathrm{site}}^{\mathrm{model}}(t)\right)^2 \qquad (2)$$

According to the wind speed ratio and change in wind direction, one minute averaged wind speed ($\bar{u}_{\mathrm{site}}$) and the direction ($\bar{\theta}_{\mathrm{site}}$) at any point along the railway is calculated from those at the measurement site $\bar{u}_{\mathrm{ref}}$ and $\bar{\theta}_{\mathrm{ref}}$.

$$\bar{u}_{\text{site}}(t) = \bar{u}_{\text{ref}}(t) \times C(\bar{\theta}_{\text{ref}}) \quad (3)$$

$$\bar{\theta}_{\text{site}}(t) = \bar{\theta}_{\text{ref}}(t) + D(\bar{\theta}_{\text{ref}}) \quad (4)$$

Prediction of gust wind speed and direction

For train operation, three second averaged gust is widely used, which means it is necessary to estimate the three second averaged maximum wind speed from 1 minute averaged wind speed. In this study, turbulence intensity ($I_u(\theta)$) was calculated as a function of the wind direction by the numerical simulation and using the turbulence intensity, gust factor ($C_R(\theta)$) is estimated as a function of the wind direction by equation (5).

$$C_R(\bar{\theta}) = 1 + k_p I_u(\bar{\theta}) \quad (5)$$

Where, k_P is a peak factor and estimated by the method proposed by Ishizaki (1983).(equation (6))

$$k_p = \frac{1}{2} \ln \frac{60\,\text{sec}}{3\,\text{sec}} \quad (6)$$

By using this peak factor, maximum gust was estimated from one minute averaged wind speed. By equation (7).

$$\hat{u}_{\text{site}}(t) = \bar{u}_{\text{site}}(t) \times C_R(\bar{\theta}_{\text{site}}) \quad (7)$$

Verification by measurement

Proposed method was verified by using the measured wind speed at five points along the JR Tohoku line near Fujita station (Fig.2). Here, measured wind speed at the point no.3 was used as a reference value and the wind speed at the other four points were estimated and compared with the measurement.

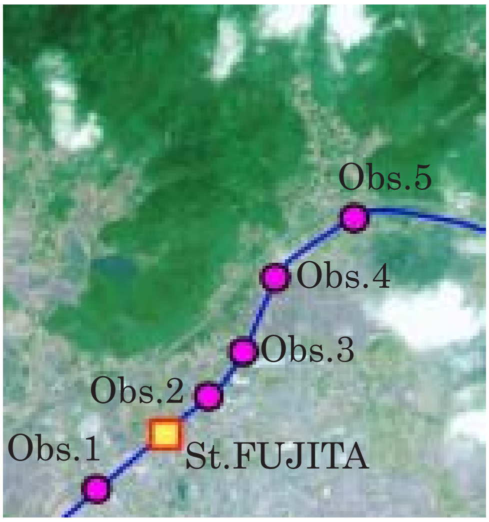

Fig. 2 five measurement points along JR Tohoku line

Figure 3 shows the estimated maximum gust at the measurement point No. 2 on the 25th of January, 2005. The strong gust can be simulated by the proposed method. Figure 4 and 5 shows the frequency distribution of the maximum gust at the measurement point No. 2 and No. 5 respectively. The annual mean wind speed at the measurement point No. 2 and 5 is the largest and the lowest among the points respectively. At both points, predicted frequency distribution shows good agreement with the measured one.

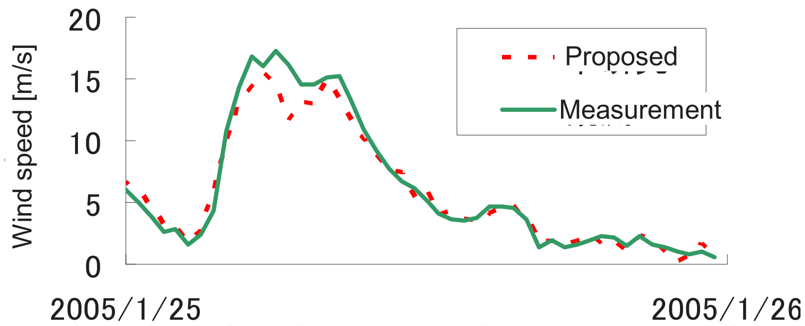

Fig. 3 The estimated maximum gust at the measurement point No. 2

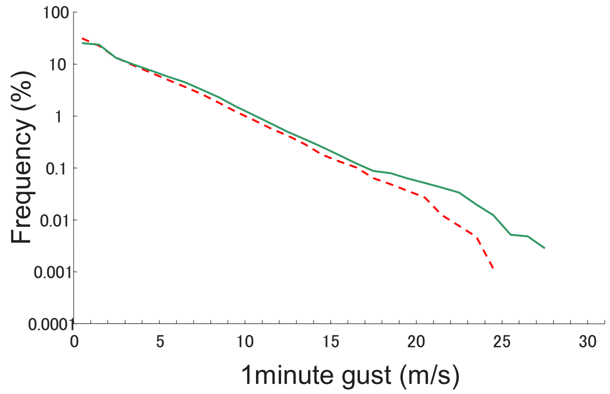

Fig. 4 Annual frequency distribution of maximum gust at the measurement point No. 2

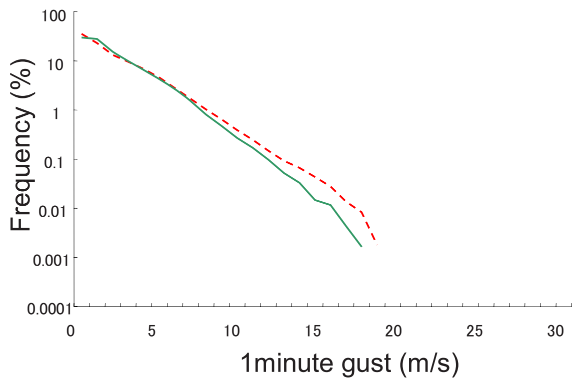

Fig. 5 Annual frequency distribution of maximum gust at the measurement point No. 5

A NEW REGULATION METHOD FOR THE TRAIN OPERATION

A new method for the prediction of regulation wind speed

In case of the conventional regulation method, which is based on the on site measurement at one site, if the measured wind speed (u^{obs}) which represents a certain section of the railway, exceeds the regulation wind speed (u^{limit}) then the operation of the train is suspended for the section. The frequency of this event P^{meas} can be estimated by

$$P^{meas} = P\left(u^{obs}{}_i > u^{limit}\right) \tag{8}$$

This method assumes that the wind speed in the section can be represented by only one site of the measurement ignoring the effect of local topography. This means that a strong wind event occurs at the point other than the measurement site cannot be detected and no regulation will be carried out. Recently in France, in order to account for the effect of local topography, a new method, in which the section is divided into certain number of sub-sections, was proposed. In this method, it is assumed that there is no correlation between the wind speeds at different sub-sections and the frequency of the strong event is evaluated by subtracting the frequency that the wind speeds do not exceed the regulation wind speed $P(u_i < u^{\mathrm{limit}})$ at any sub-sections from 1.

$$P^{\text{no-cor.}} = 1 - \prod_i \left[1 - P(u_i < u^{\mathrm{limit}})\right] \tag{9}$$

However, in reality, the correlation between the wind speeds at different sub-sections exists and this method might overestimate the frequency of the suspension of the train operation.

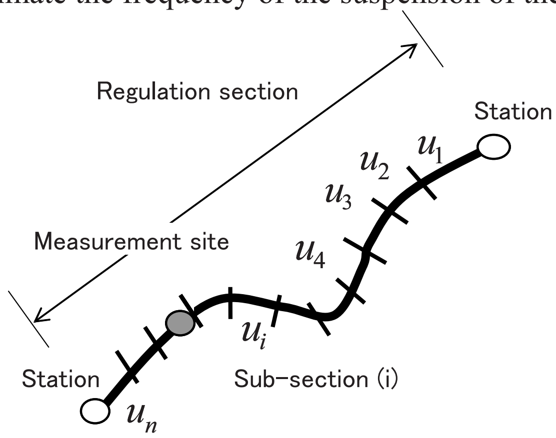

Fig. 6 The regulation section and sub-section

In order to solve these problems, in this study, the operation of the railway is suspended when the wind speed at any sub-section exceeds the regulation wind speed u^{limit}.In this case the frequency of strong event will be expressed as follows:

$$P^{\text{propsed}} = P\left(\max(u_i) > u^{\mathrm{limit}}\right) \tag{10}$$

By this method, the correlations between the sub-sections are considered and more adequate train regulation will be made possible.

Verification by measurement

Consider sub-sections whose representing point is the five measurement site described above and frequency of the strong event was estimated using three different methods described above. Figure 7 shows the frequency of strong event in which the wind speed exceeds 25m/s. The measurement value is also shown as the highest value of the measurement exceeds 25m/s.

Conventional method based on on-site measurement at one site underestimate the frequency of the strong wind event. This is because of the case in which wind speed does not exceed the regulation wind speed at the measurement site while it exceeds at the other sites. The other conventional method in which the correlation of the wind speed between the sub-sections overestimate the frequency of strong wind event. In reality, the correlation of the wind speeds between the sub-sections causes strong wind occur simultaneously.

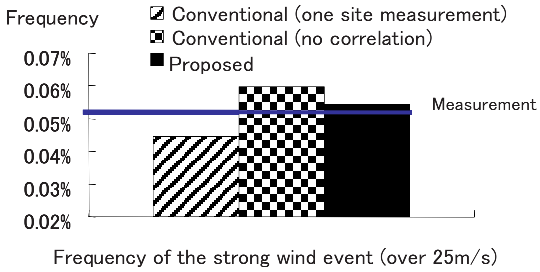

Fig. 7 Frequency of strong wind

The effect of the interval of the sub-region

In this method, the interval of the sub-section will affect the result. In order to investigate the effect of the interval of the sub-section, frequency of strong wind event was calculated for different intervals of the sub-sections. Figure 8 shows the frequency of the strong wind event for different intervals of the sub-sections.

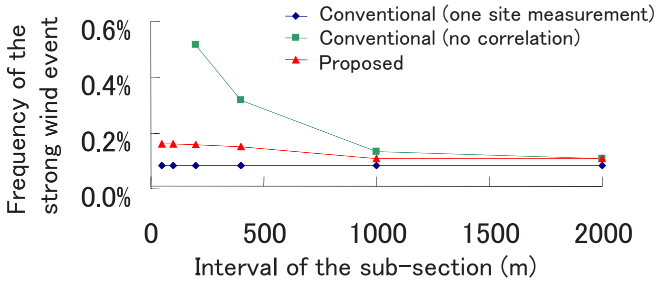

Fig. 8 The frequency of strong wind event and the interval of the sub-section

In the method proposed in this study, the frequency does not change considerably for the intervals of less than 2000m. In the method where the correlations among the sub-sections are ignored, when the intervals of the sub-sections are around 2000m then the frequency shows similar values with proposed method. This is because in France, the topography is moderate compared to Japan and 2000m can be used as the intervals of the sub-sections and in their case, the assumption of no correlation among the sub-sections are applicable. But in case the intervals of the subsections become shorter, this method over estimate the frequency of the strong wind event considerably.

THE EFFECT OF THE WIND DIRECTION AND THE WIND FENCE

As the turnover wind speed for the train changes considerably depending on the wind direction, more adequate train operation is expected by considering the wind direction. Furthermore, the effect of the wind fence has to be verified.

The outline of the method

To consider the effect of the wind direction, wind direction factor $C(\phi)$ which account s for the reduction effect of the turnover wind speed of the train.

$$C(\phi) = \frac{W_C(\phi_{DNGER}, V)}{W_C(\phi, V)} \tag{11}$$

Where, $W_c(\phi, T, V)$ is the overturning critical wind speed which is a function of the relative angle between the train and the wind ϕ and the train speed V .φ_{DANGER} は is the angle between the train and the wind at which the overturning critical wind speed has the smallest value, i.e. the most dangerous direction. In this study, the train speed V is assumed to be 120km/h. The effect of the wind fence is described by a wind fence factor $C(\phi)$.

$$C^*(\phi) = \sqrt{(C_n \sin\phi)^2 + (C_r \cos\phi)^2} \quad (12)$$

Where, $C_n = 0.83$ and $C_r = 1.0$ is the reduction factor for the wind component perpendicular and parallel to the wind fence respectively. These wind direction factor and the wind fence factor are multiplied to the predicted wind to estimate the overturning critical wind speed considering the wind direction and the wind fence.

Results

Using these methods, the frequency of strong event in which the wind speed exceeds the regulation wind speed considering the effect of wind direction and wind fence (Figure 9). By considering the effect of wind direction and the wind fence, the frequency of strong wind event decreases considerably and as a result, the frequency of regulation will be decreased without decreasing the safety of the train operation. Furthermore, the quantitative analysis of the effect of the wind fence was made it possible to determine the site, length and the direction of the wind fence quantitatively.

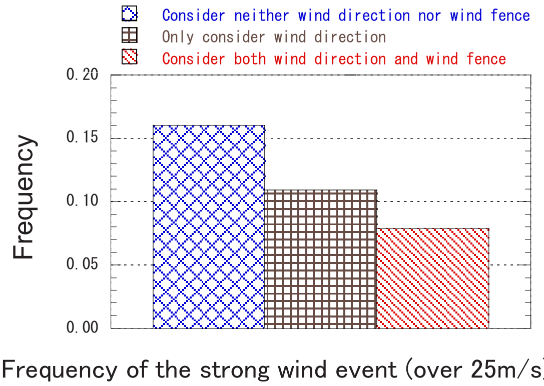

Fig. 9 The frequency of the strong wind event

SUMMARY

In this study, a new method for the prediction of the wind speed along the railway was proposed by c ombining numerical simulation and the measurement. In addition, a new train regulation method considerin g the difference of the wind speed in the regulation section, the correlation of the wind speed between su b-sections, wind direction and wind fence was proposed. Following results were obtained.

1) Proposed wind prediction method can predict strong wind event as well as the effect of local topography resulting the accurate prediction of the frequency distribution of wind speed.
2) Proposed method for the estimation of frequency of strong wind event shows better agreement with the measurement compared to the conventional methods.
3) When the effect of wind direction and the wind fence is considered, the frequency of the train regulation due to strong wind event decreased.

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