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Analysis of Wind Turbine Fatigue Loads for Proper Estimation of Offshore Turbulence Intensity

Yukiko TSUGAWA[1], Noboru SAKAMOTO[2], Shozo KAWASAKI[2], Chuichi ARAKAWA[1], Makoto IIDA[1]
[1]The University of Tokyo, Japan, [2]Electric Power Development Co.,Ltd.

東京大学 THE UNIVERSITY OF TOKYO

Abstract

Offshore turbulence intensity arises by following a mechanism unique to offshore flow[1]. However, the normal turbulence model in IEC 61400-3[2] has not been efficiently established as a proper model for offshore turbulence intensity. Turbulence intensity is estimated as a 90% quantile in the model on the assumption that its distribution in wind speed bins follows a log-normal distribution, as is also assumed in IEC 61400-1[3]. In actual fact, the distribution in some offshore sites differed from the assumption[4]. Therefore, to operate offshore wind turbines more efficiently, establishing a more appropriate way to estimate offshore turbulence intensity is necessary.

This research presents an analysis of the effect of variable of turbulence intensity on wind turbine loads in offshore sites where turbulence intensity varies between seasons. The analysis is performed based on field data observed off the coast of Kitakyushu, Fukuoka, Japan. As results of the analysis, the load direction that is most affected by the variability of turbulence intensity was revealed.

Furthermore, the result suggested a new offshore turbulence model focused not only on the wind conditions but also on the wind turbine loads. The model estimated turbulence intensity as a 99% quantile in addition to the 90% quantile of the conventional method. It is concluded that the model could grasp the trait of the load direction which is highly susceptible to variability of turbulence intensity.

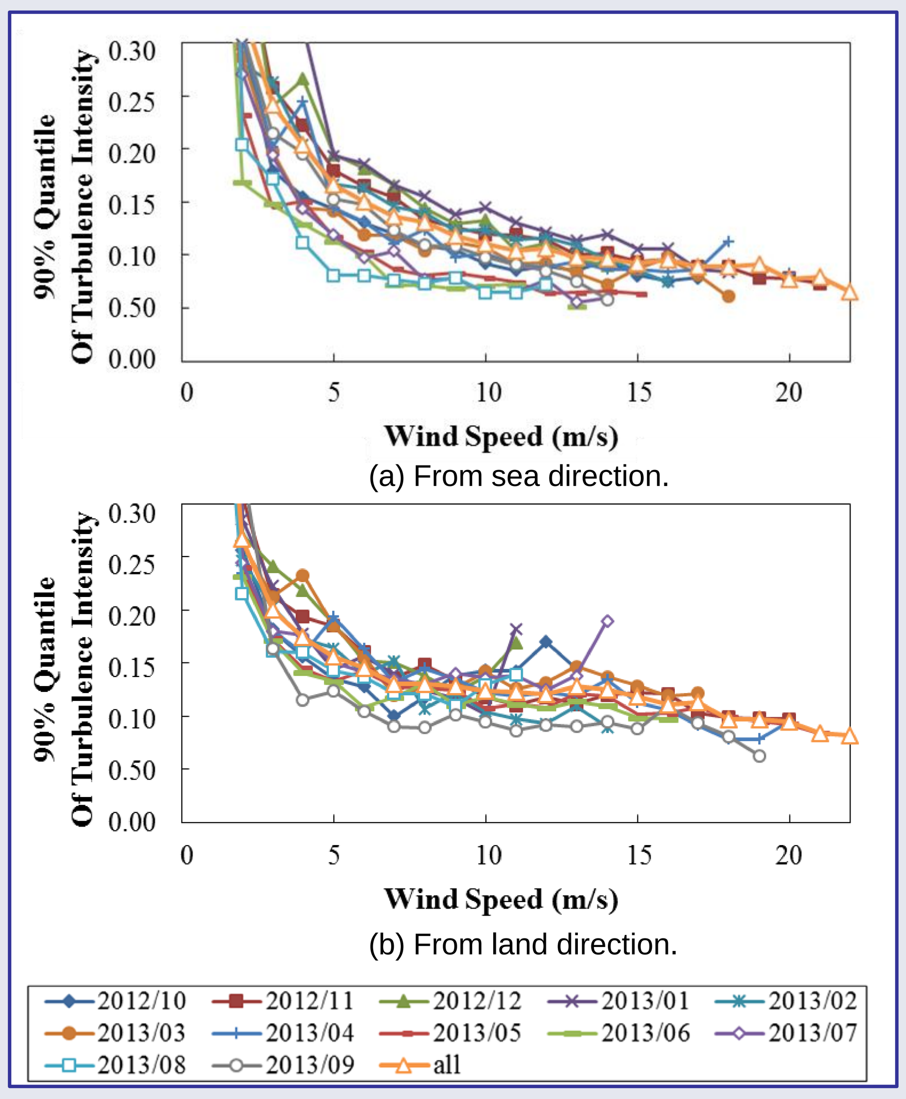
Objectives

The objective of this research is to estimate offshore turbulence intensity based not only on wind conditions but also on wind turbine loads influenced by offshore wind conditions. First, based on the field data in an offshore site where turbulence intensity is variable between seasons, the effects of variability of turbulence intensity on wind turbine loads were analyzed. Next, a new estimate of the turbulence intensity was suggested.

Methods

Wind conditions (Turbulence intensity)

The observation site was 1.4 km offshore. The wind from the land direction was affected by the character of the ground. Hence, the wind was different depending on direction (from the sea or land direction). The turbulence intensity of the wind from the sea direction is variable across seasons; it is high in winter and low in summer.

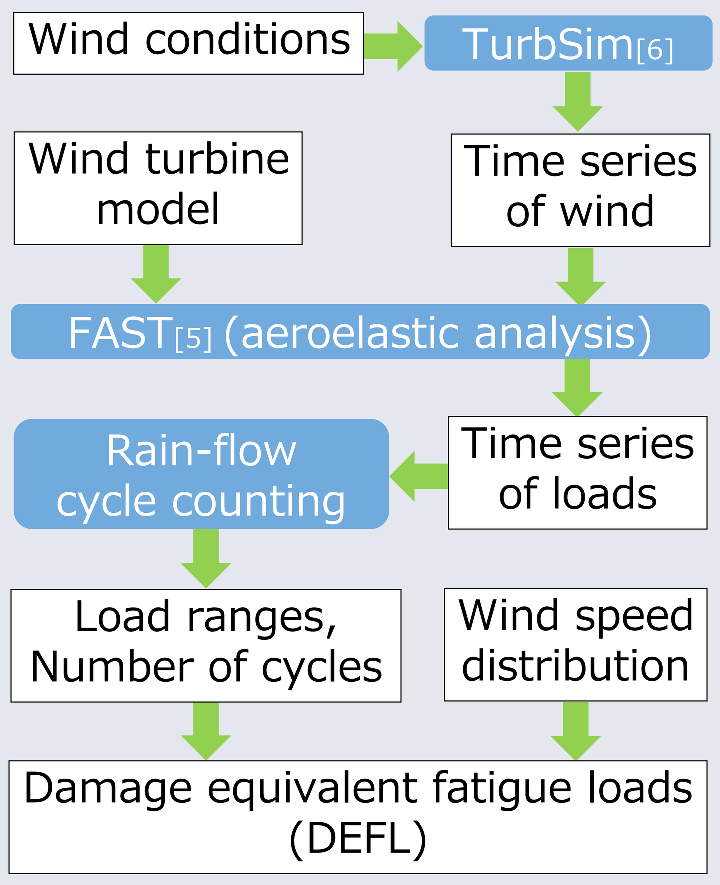


90% quantile of turbulence intensity for each month.

Analysis flow

Based on the turbulence intensity of the wind from different directions, aeroelastic analyses were performed using FAST[5], a software developed by NREL .

The load amplitudes F_i and the number of cycles n_i were counted based on the rain flow method.



Damage equivalent fatigue loads (DEFL)

A comparison of the ways of estimating turbulence intensity was performed with damage equivalent fatigue loads (DEFL). DEFL means the summation of converted load amplitudes for the standard number of cycles N_o:

$$DEFL = \sqrt[m]{\frac{\sum_i F_i{}^m n_i}{N_0}}$$

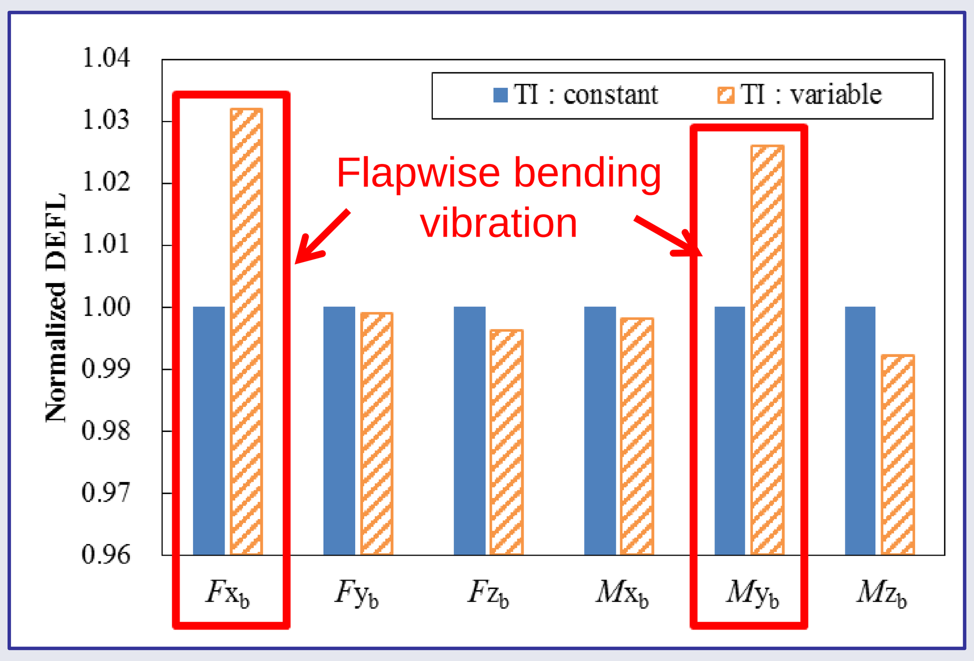
where m is the material fatigue exponent and N_o is the frequency for the lifetime of the wind turbine. In this research, the value of m was 10 (glass composite) in the blade root and the value of N_o was 2.1 × 10[7].

Results

Effect of the seasonal variability of turbulence intensity in DEFL

Two cases were compared; one where the turbulence intensity was constant for all seasons (TI: constant) and the other where turbulence intensity was variable between seasons (TI: variable).

DEFL values caused by flapwise bending vibration (F_{xb} and M_{yb}) were approximately 3% larger when the turbulence intensity was variable. These load directions were susceptible to fatigue due to the variability of turbulence intensity.

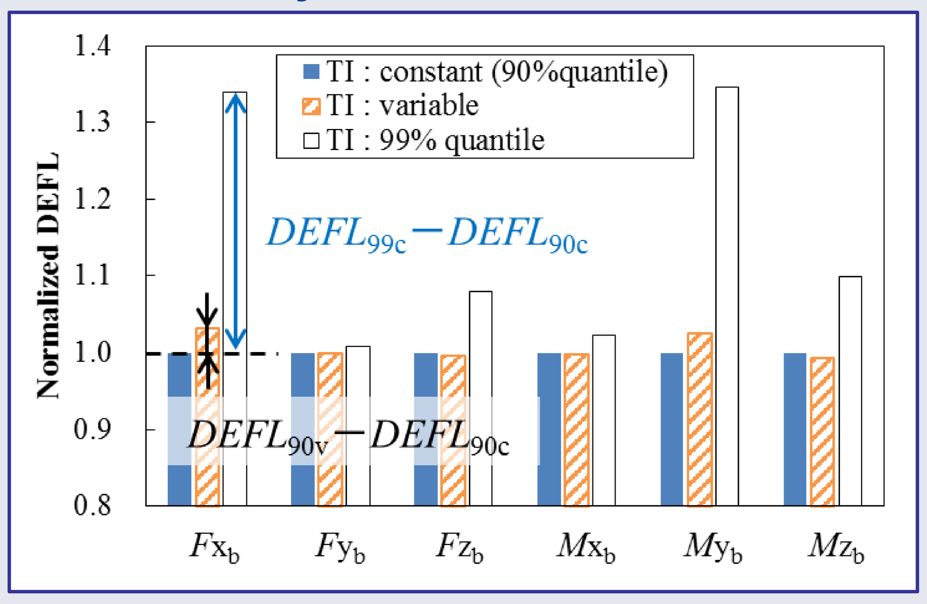


Effect of the seasonal variability of turbulence intensity on normalized DEFL in the blade root. Each value was normalized by the value of the “TI: constant” case.

Suggestion of a new estimate of turbulence intensity

DEFLs analyzed following a 99% quantile of turbulence intensity were able to grasp the trait of the load direction, which was highly susceptible to variability of turbulence intensity.

The difference in the DEFL caused by the variability of turbulence intensity was regarded as x times that between the 90% and 99% quantiles.

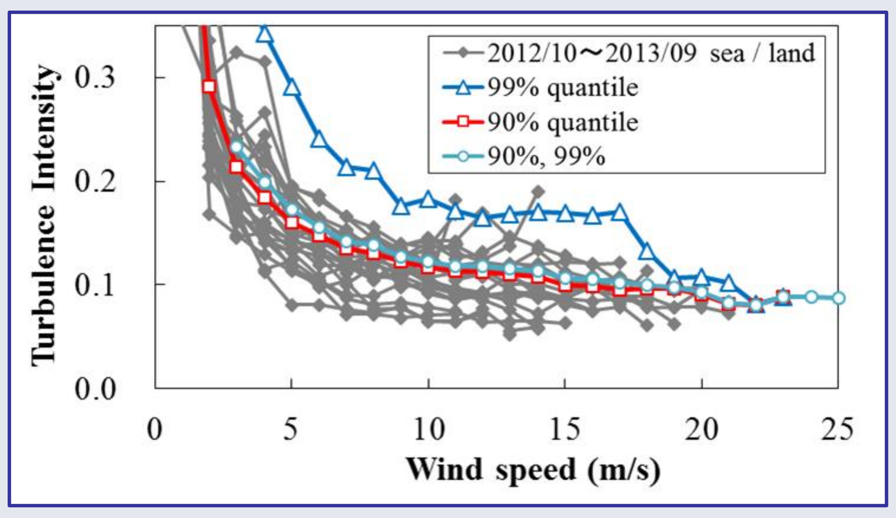


Normalized DEFL calculated based on a 99% quantile of turbulence intensity in the blade root.

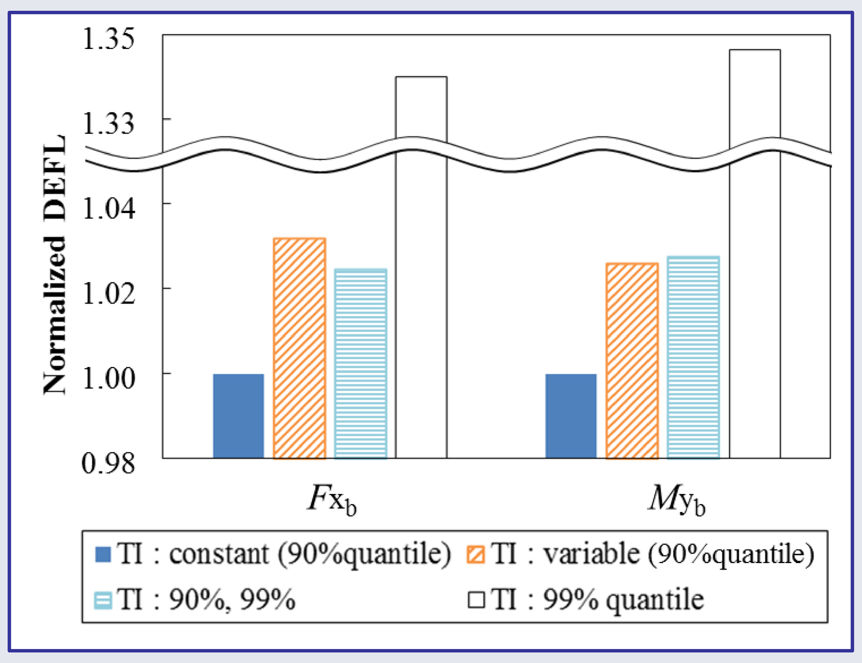
$$DEFL_{90v} - DEFL_{90c} = x(DEFL_{99c} - DEFL_{90c})$$

By replacing DEFL with TI (turbulence intensity), a new estimate of turbulence intensity considering a 99% quantile can be defined as

$$TI_{90,99} = (1-x)TI_{90} + xTI_{99}$$



Comparison of estimated turbulence intensity between different methods. The new estimation appears as the green line.



Normalized DEFL in the flapwise bending direction calculated based on the new estimate of turbulence intensity in the blade root.

The DEFL calculated based on the new estimation method can describe the effect of the variability of turbulence intensity.

Conclusions

The variability of the offshore turbulence intensity has a large effect on the fatigue load in flapwise bending direction in the blade root.

The estimate based on both the 90% and 99% quantiles can describe the variability of turbulence intensity better than that based on only the 90% quantile.

Offshore turbulence intensity needs to be estimated in further detail instead of by the conventional method, such as by considering the 99% quantile.

References

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