IMPACT ASSESSMENT OF TERRAIN TURBULENCE TO WIND TURBINE FATIGUE

Soichiro. Kiyoki[1], Takanori. Uchida[2], Yasushi. Kawashima[3] and Katsutoshi, Kondo[1]

[1]Hitachi, Ltd.

[2]Kyushu University

[3]West Japan Engineering Consultants, Inc.

The fatigue load and the wind condition of the wind turbine built in a complex terrain were measured and evaluated. The fatigue load was increased by the severe wind condition caused not only by the mountains and the wind turbine wake but also by small terrain changes in an upstream of complex terrain. In addition, in order to establish the technique to predict the fatigue load in complex terrains, the method in which wind speed time history from the wind analysis software "RIAM-COMPACT" using LES was reproduced as an input of the wind turbine aero-elastic analysis software "BLADED" was developed.

Keywords: complex terrain, turbulence flow, fatigue load, field test

INTRODUCTION

An electric power source is essential in the modern life. However, our so-far main power source, fossil fuel has environmental and depletion problems, and so there is a compelling need for the new power sources. Although wind power generator system is one of promising power sources, the durability evaluation is difficult due to utilizing natural wind and accidents become to prevent the spread of wind turbine.

For the evaluation method of durability in the construction site, the engineering work is being performed to create a new standard (IEC61400-15). But it is reality that the knowledge is insufficient for the wind condition and the durability prediction in complex terrain. In order to help solving the above problems, the wind condition and fatigue load in complex terrain were evaluated by actual measurement and the prediction technology for these was attempted to establish in this report.

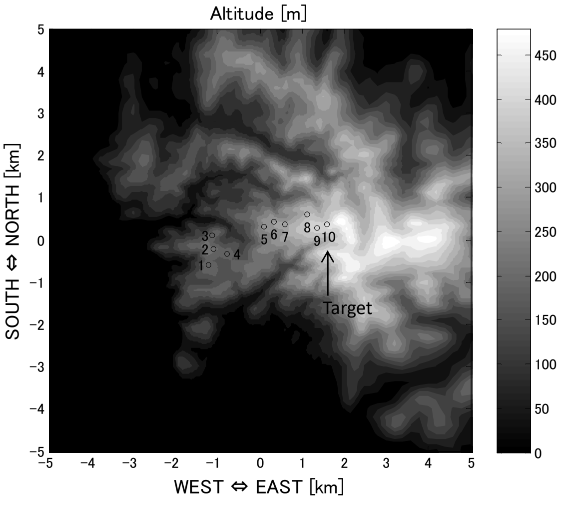

Figure 1. Altitude Contour and WT Positons

FIELD TEST EVALUATION

Test Site and Wind Turbine

Field test was held with the wind turbine built in complex terrain 3 km away from coast line. Altitude contour and wind turbine positions are shown in figure 1. At east side of target wind turbine, there is a mountain of almost same height as the top of the wind turbine rotor. Wind turbine is HTW2.0-80 downwind turbine made by HITACH, which has 2MW rated power, 80m rotor diameter and 60m hub height. The wind turbine is designed as 10m/s average wind speed, IEC category A turbulence intensity and 0.2 wind shear α for blades.

Measurement

Flapwise bending moments (MYS) of 3 blades were measured by installed electrical strain gages at pressure and suction side of blade root section. Wind speed and wind direction were measured on the nacelle using 3 cup type anemometer and wind vane. Wind speed was corrected by the correlation between nacelle and mast wind speed at flat terrain site. The measurement term is from Nov. 3rd, 2015 to Mar. 17th, 2016 and each parameter was sampled at 50Hz. As a result of filtering abnormal data, the valid data was about 80 days.

Wind Condition

The measurement results of turbulence intensity in each wind direction sector are shown in figure 2. Here it is necessary to note that the turbulence intensity was acquired by nacelle wind speed. Because the target wind turbine is downwind type which has nacelle anemometers in front of rotor, the measurement accuracy is considered to be relatively high[1]. In the main wind direction (0 deg), turbulence intensity is lower than design value. In the wind direction of the wind crossing mountain (90 deg) and wake wind (270 deg and 300 deg), turbulence intensity is higher than design value. An attention

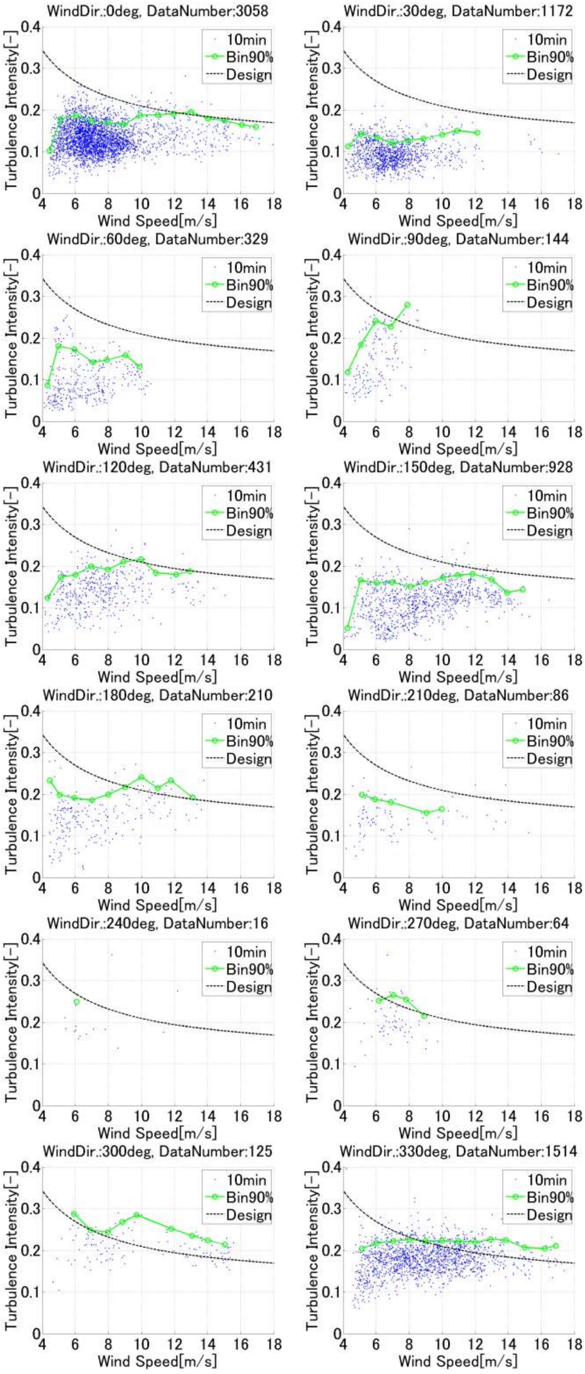

Figure 2. Turbulence Intensity

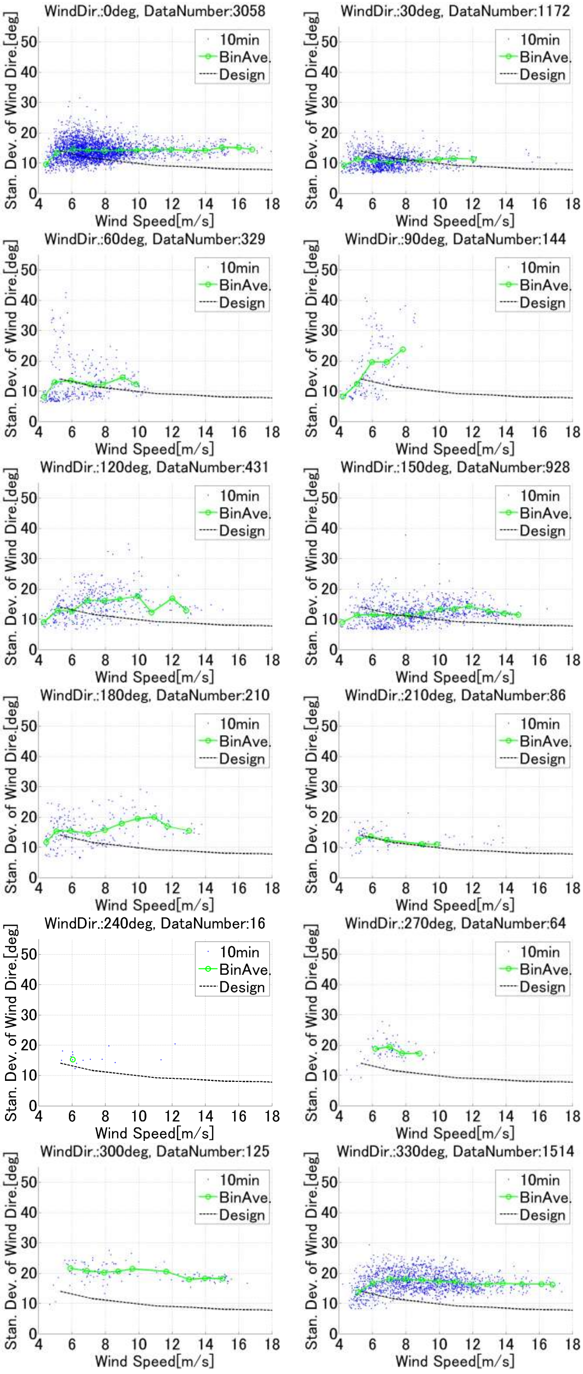

Figure 3. Standard Deviation of Wind Direction

should be paid to the fact that turbulence intensity is high in the wind direction of 330 deg which is assumed not to be so severe from the upstream terrain.

The measurement results of standard deviation of wind direction in each wind direction sector are shown in figure 3. It is generally higher than the design value based on IEC standard. The reason is considered to be the difference of turbulence structure between complex terrain and flat terrain. The tendency is almost same as turbulent intensity.

Fatigue Load

The measurement results of DEL (Damage Equivalent Load) of blade flapwise bending moment in each wind direction sector are shown in figure 4. In the DEL calculation [2], the parameter “m”, which is the slope of S-N curve, was set to 10. DEL was normalized by the design value at 12m/s. The data of only blade 1 was shown here but the data of other blades have shown almost the same result. Measurement result was lower than design value in main wind direction (0 deg). But in 90 deg, 120 deg, 180 deg, 270 deg, 300 deg and 330 deg of wind direction sector, measurement result exceeds the design

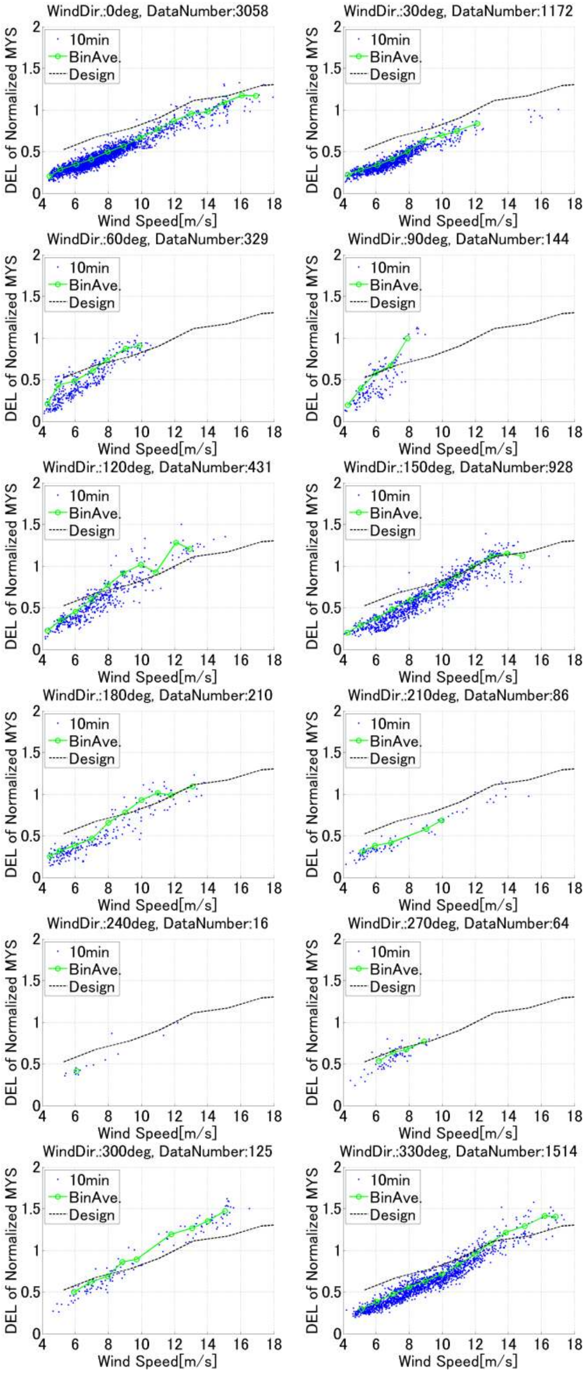

Figure 4. DEL of Normalized MYS

value in the part of wind speed. This trend is in good agreement with turbulence intensity and wind direction fluctuation.

Although the above analysis was for each wind direction and wind speed, here the durability evaluation integrating them was performed. As a result, even in the harsh analysis, durability was more than 20 years which is design service life.

PREDICTION TECHNIQUE

Technique Outline

In order to establish the technique to predict the fatigue load in complex terrain, the method was developed in which wind speed time history from wind analysis software “RIAM-COMPACT” [3] using LES was reproduced as input of wind turbine aero-elastic analysis software “BLADED” [4].

Methodology

First, the wind speed at the BLADED grid was calculated by the result of RIAM-COMPACT. Here, linear interpolation was used for interpolation and the nearest value was used for extrapolation (see figure 5). Furthermore, because BLADED cannot read time series wind data of 3 components and 2 dimensions (on rotor plane), the input method in this study for the items possible to input BLADED is shown in table 1.

Table 1. Input method of wind speed to BLADED.

Input Parameter	Input Method
Fluctuation component (3dimension)	Fluctuation component excluded average value
Average wind speed (1point)	Value at wind turbine hub position
Vertical wind speed shear (1line)	Value at wind turbine center
Vertical wind direction shear (1line)	No input

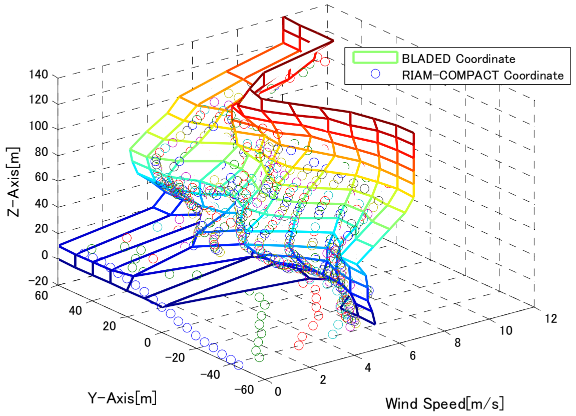

Figure 5. Inter and Extrapolation of Wind Speed

Wind Speed Reproducibility

For east wind (wind direction 90deg) in which fatigue load was severe, input wind and fatigue load by the method were evaluated. The comparisons of longitudinal wind speed time history at 9 points in turbine rotor are shown in figure 6. The input wind speed of BLADED is almost consistent with the output of RIAM-COMPACT although there is slight difference on the edge of rotor due to no input of horizontal wind shear and input at only 1 point of vertical wind shear. Although this paper does not include, it was confirmed that the lateral and vertical components of wind speed are almost consistent between BLADED input and RIAM-COMPACT output.

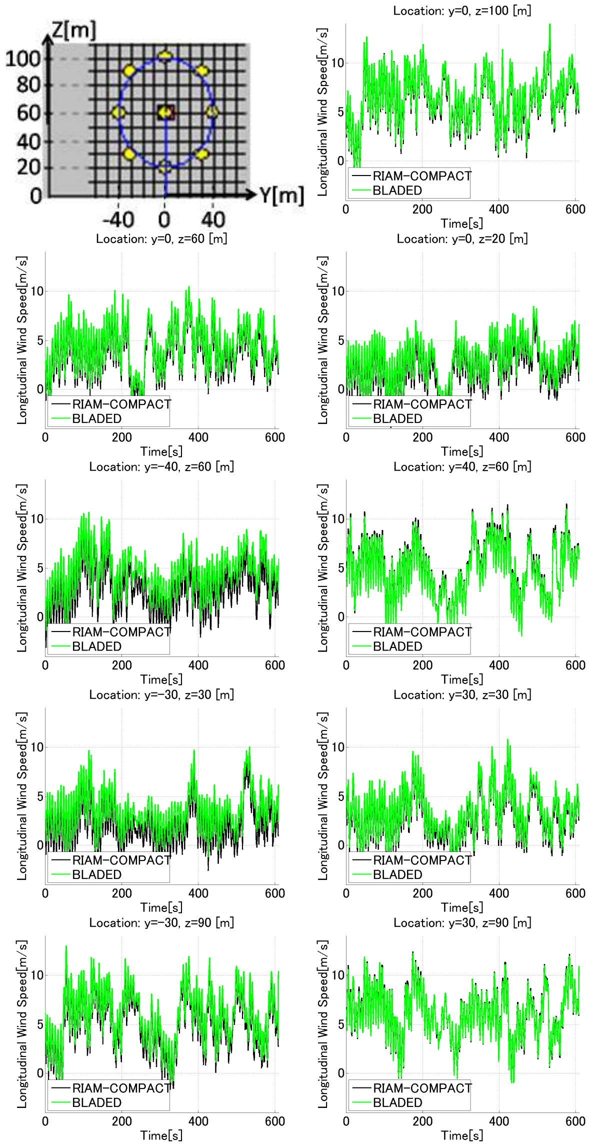

Figure 6. Wind Speed Comparison (U-component)

Prediction Accuracy

Aero-elastic simulation was done using BLADED with the input of wind speed shown in figure 6. The comparison of the blade flapwise bending moment between the analysis and the measurement are shown in figure 7. Average shows in good agreement but DEL of simulation shows 1.8 times higher than DEL of measurement. In the future, the accuracy of the analysis will be improved by evaluating the wind speed and the wind turbine behavior.

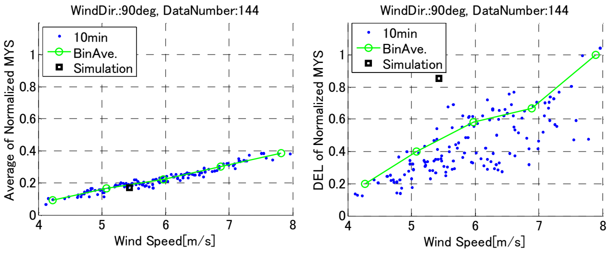

Figure 7. Evaluation of Analysis Accuracy

CONCLUTION

The outcomes of this study are followings.

(1) The load measurement results in complex terrain which are rarely reported were shown with the wind condition measurement results.
(2) It was found that the fatigue load increases in the severe wind condition caused not only by mountains and wind turbine wake but also by small terrain changes in an upstream of the complex terrain.
(3) The fluctuation of the wind direction was larger than the condition based on IEC standard.
(4) The prediction method for the fatigue load in complex terrain was developed. The wind speed time history of the wind analysis software “RIAM-COMPACT” using LES was reproduced well as an input of the wind turbine aero-elastic analysis software “BLADED”.

In the future we are planning to research followings.

(1) Wind condition will be evaluated more accurately with 3D ultrasonic anemometer without movable parts and remote sensing device possible to measure vertical distribution.
(2) The prediction accuracy of fatigue load will be increased by verifying the prediction accuracy of wind speed and wind turbine behavior.
(3) The characteristics of wind in complex terrain which greatly affect the wind turbine fatigue load will be identified.

References

[1] S. Kiyoki and S. Yoshida, “Turbulence Measurement by Nacelle Anemometer of Downwind Turbine”, *European Wind Energy Conference 2007*, 2007.

[2] International Electrotechnical Commission, “Wind turbines- Part 13: Measurement of mechanical loads”, *IEC61400-13*, 2015.

[3] Takanori Uchida and Yuji Ohya, Latest Developments in Numerical Wind Synopsis Prediction Using the RIAM-COMPACTR CFD Model -Design Wind Speed Evaluation and Wind Risk (Terrain-Induced Turbulence) Diagnostics in Japan, *Energies*, Vol.4, pp.458-474, 2011.

[4] Garrad Hassan and Partners, BLADED ver.4.2.0.83, 2012.