

## FLUCTUATING WIND LOAD ANALYSIS OF WIND TURBINE TOWER

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During the development of the Guideline for Wind Turbines in Japan, measurement campaigns on wind conditions and loads at existing wind turbine sites were carried out. From the viewpoint of design loads, one important item is the unsteadiness of wind turbine loads which determines the maximum value. The fluctuating wind turbine loads were evaluated focusing on the above points. Its properties are expressed as gust factors of loads. The gust factor of wind load shows minimum value near the rated wind speed and increases with wind speed toward the cut out wind speed.

**Keywords:** wind turbine, wind load, tower, turbulence, gust factor

### BACKGROUND

The Guideline for Wind Turbines in Japan<sup>[1]</sup> has been under development in order to introduce more turbines in Japan. One technical concern is that the design wind loads are affected by the site wind characteristics.

In Japan, the wind is supposed to be more turbulent by complicated terrain and extreme wind would be more severe by typhoons. When installing wind turbines, it is important to select sites where mean wind speed is high enough to harness more energy productions as well as to select wind turbines which can withstand wind conditions such as extreme wind speeds and turbulences at the sites.

The Guideline describes the procedure of selecting wind turbines in terms of wind conditions and clarifying problems to be solved. However, wind turbines are considered to have different characteristics in wind loads when compared to other big structure. Most important factor would be that wind turbines often change its shapes during operation with rotor movement, pitch movement and yaw movement. Moreover, these operations would be continuously changed according to the unsteady wind conditions.

During the development of the Guideline, measurement campaigns on wind conditions and loads at existing wind turbine sites were carried out. From the viewpoint of design loads, one important point is the unsteadiness of wind turbine loads which determines the maximum value. In other effort to establish wind turbine design codes from the architectural point of view<sup>[2]</sup>, these unsteadiness of wind loads has been modeled by mathematical equations to express its characteristics depending on various turbines parameters.

Therefore, it is indispensable to understand the wind turbine loads in order to establish adequate

design way for wind turbines. Recently, site measurement has been applied to real wind turbines and the wind loads characteristics has been examined<sup>[3-5]</sup>. Through these researches, it has become clear that wind load acting on wind turbines varies according to the wind speed. However, it is not clear enough how each factor affects the wind loads.

For that purpose, the examination based on measurement data from existing real turbines is still important.

### OBJECTIVES

In this paper, wind loads acting on wind turbines are investigated using data obtained from large horizontal wind turbines. The data was analyzed especially from the viewpoint of its unsteadiness caused by the fluctuation of natural wind. Its properties are expressed as gust factors of loads. Also data from two different sites are compared with each other.

The results would be important to find more rational value of wind turbine design loads.

### SITE MEASUREMENTS

#### Measurement Procedure

The data in this paper was obtained in the project funded by New Energy and Industrial Technology Development Organization. The descriptions about target site and measurement contents are described in [6] and [7]. At each of the target sites, a meteorological mast was installed within one or two rotor diameter distance from the turbine. The meteorological masts were equipped with wind speed and direction sensors. The measurements of loads on the turbine structural components were also performed using strain

gauges. The measured quantities include tower bending moments in two perpendicular directions. Figure 1 shows the image of site measurement.

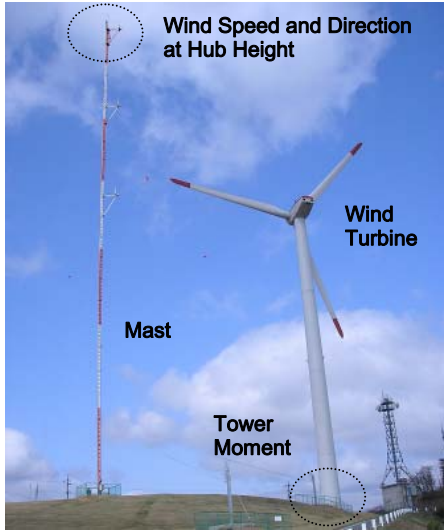


Figure 1 Measurement at 1MW turbine.

### Data Analysis

In the analysis, measured data was analyzed statistically with each 10 minute data set. Wind speed from meteorological mast at hub height was used as reference wind speed  $w_s$ . Turbulence intensity  $I_u$  was also calculated to show the inflow condition. The measured wind loads at tower base was processed to show the total bending moment  $M_{xytb}$  and the value was normalized with that at rated wind speed. The maximum as well as the mean value were derived for each 10-minute data set. The relative magnitude of the maximum value compared with the mean value is defined as gust factor  $GF$ , which shows the unsteadiness of the wind load. Finally, the average (binned value) of turbulence intensity  $I_u$  and moment  $M_{xytb}$  was calculated for each 1-m/s bin of wind speed.

Figure 2 shows example of time history plot of measured data. The data was taken for one day when the wind speed was relatively high. Both the wind speed and the power output are increasing gradually. The wind speed continues to increase to the end while power output suddenly turns to zero around 21:00. This shows the wind turbine stopped power production and turns into idling mode because of the high wind speed after 21:00. At the same timing, the tower moment also shows sudden decrease. This means the wind load acting on wind turbine mainly depends on operating condition; the turbine is producing power or in idling mode.

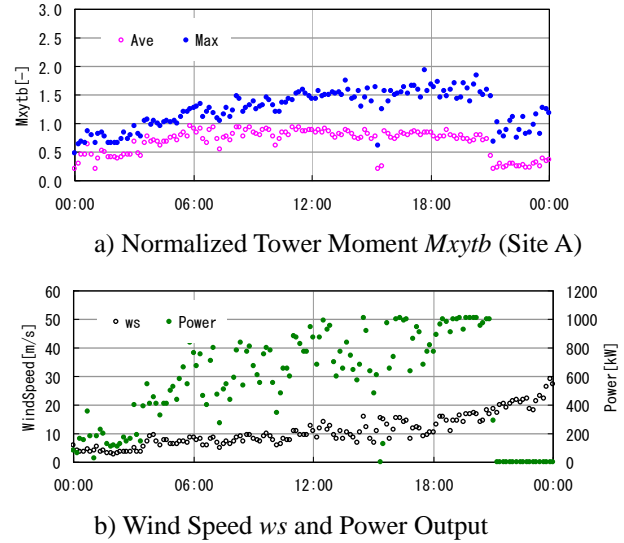


Figure 2 Time History of Measured Data (Site A)

## RESULTS

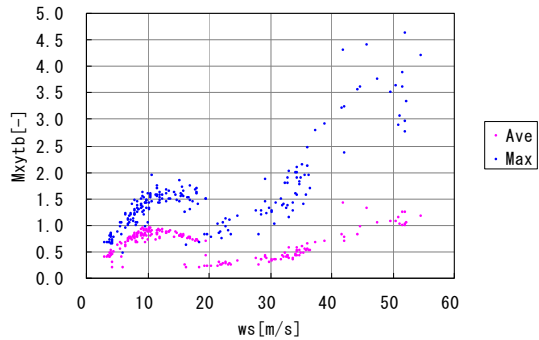
### Analyzed Data

Figure 3 shows the a) tower moment, b) gust factor  $GF$  and c) turbulence intensity with mean wind speed as horizontal axis. In figure a), the tower moment has a gap around 18m/s. This is because of the difference if the turbine is operating or not. Above 18m/s, the moment increases with the wind speed, which is common in the wind loads of general structures. However, below 18m/s, the moment takes peak value around 12m/s, which correspond with the rated wind speed. This is unique with wind turbine structure whose wind load is mainly acting on the rotating rotor under power production mode. In figure b), the vertical axis  $GF$  shows gust factor. The data is divided into tow groups if the turbine is in power production mode or in idling mode. The gust factor almost doubles when the wind speed increases and the turbine switches from power production mode to idling mode. As seen in figure c), the turbulence intensity decreases with the increase of wind speed when the above data was obtained.

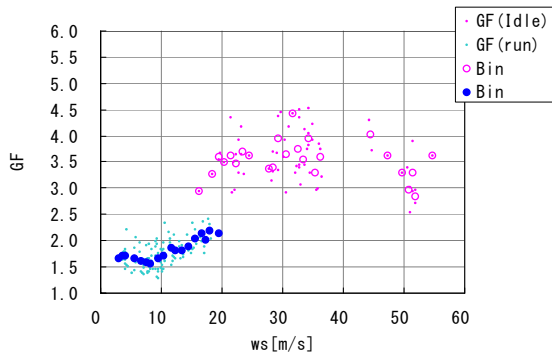
Figure 4 shows data from another site. In figure a), the gust factor decreases with the increase of the wind speed toward the rated wind speed (around 12m/sec in this case). However, it begins to increase when the wind speed exceeds above the rated value. These values are dependent on turbulence intensities included in the natural wind. The turbulence in this case shows different tendency from that of Site A as shown in Figure 3 c).

In other structures which is rigid and with no movable parts like buildings and bridges, the gust factors has rather constant values and only affected by the turbulence intensity. The above tendencies

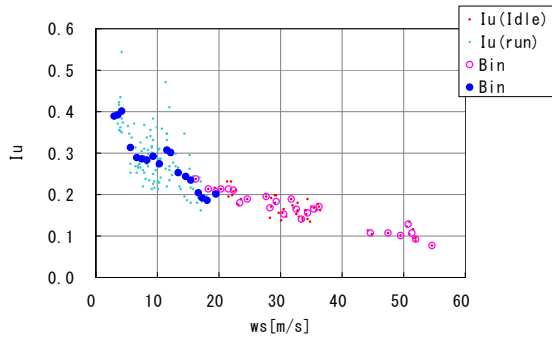
measured in large wind turbines from two sites are quite different from those of other structures. Therefore it is important to take appropriate GF value at different wind turbine operation.



a) Normalized Tower Moment  $M_{xytb}$  (Site A)

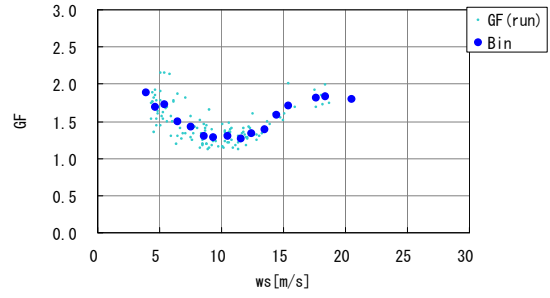


b) Gust Factor  $GF$  (Site A)

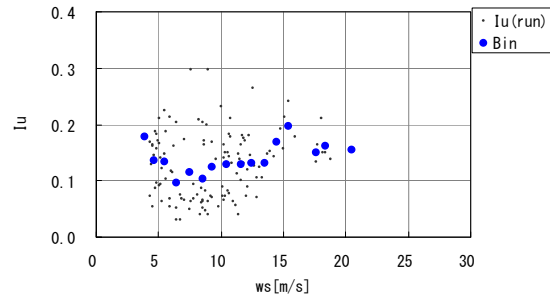


c) Turbulence Intensity  $I_u$  (Site A)

Figure 3 Wind speed and loads for Site A



a) Gust Factor  $GF$  (Site C)

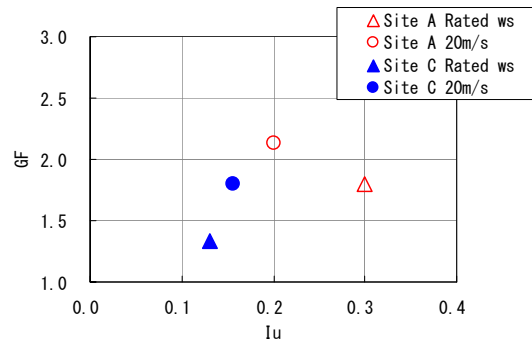


b) Turbulence Intensity  $I_u$  (Site C)

Figure 4 Wind speed and loads for Site C

### Discussions

From the measurement data at two wind turbine sites, it is found that the gust factors which show the unsteadiness of the wind loads show different tendencies for both cases. The important factor in wind turbines is the operating conditions of the wind turbines. Furthermore, the gust factor is also known to be affected by the turbulence intensity which may differ on each site and climate conditions. Figure 5 shows how the gust factor is affected by the turbulence at two different wind speeds. In each wind speed, the gust factor is larger when the turbulence is larger. However, the magnitude of gust factor is different depending on the wind speed.



\*:The turbine is in power production mode.

Figure 5 Gust Factor of Tower Loads

## CONCLUSIONS

Wind load of large wind turbine towers has been investigated through site measurement. Because of the different operational modes depending on the wind speed, wind turbines shows complicated characteristics in the view of fluctuating wind loads under natural wind. The gust factor of wind loads, which plays important role for determining the design loads, shows minimum value near the rated wind speed and increases toward the cut out wind speed. Furthermore, when the wind speed increases and the turbine becomes idling, the factor shows sudden increase.

These information would be useful for more reliable design of wind turbines.

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