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DESIGN WIND LOADS ON A WIND TURBINE FOR STRONG WIND

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Abstract

A method is proposed to estimate wind force on blades, a hub and a nacelle and that on a tower of a large wind turbine by an ordinal base balance technique measuring shear force and overturning moment at the base of the tower. The method is used to determine the proper equivalent design wind loads on the blades and the towers corresponding with the maximum response of the wind turbine due to gust in severe storms. The maximum over turning moment is induced when the wind force on the blades reaches to the peak instantaneously. It is emerged that the feathering of the blade is effective even when the wind attacks to the blades at right angles.

1 INTRODUCTION

According to growing concern on global warming, it is expected to use more clean energy including wind energy. Constructions of large wind turbines are rapidly increasing in 21st century. On the other hands, wind induced damages of wind turbines are increasing particularly in sever wind storm dominant area. In order to promote the spread of wind turbines, it is necessary to establish the proper wind resistant design method for severe wind storms.

This paper describes an estimate of wind loads on a modern large wind turbine for the wind resistant design. In order to perform a detail structural analysis for the tower, the wind force on the blades including a hub and a nacelle (hereafter called as the blades) and the wind force on the tower must be estimated separately and simultaneously. A method is proposed to estimate these two wind forces from the ordinal base balance technique measuring shear force and overturning moment at the base of the tower. The method can separate properly the mean wind forces, but also the instantaneous wind forces. As the method has an advantage to adjust any distribution of the wind force on the tower, it is suitable for the detail stress analysis of the joint elements of the tower. The peak wind loads on the blade and the tower were estimated from the wind tunnel test using a vibration model.

2 METHOD TO ESTIMATE WIND FORCES ON BLADES AND TOWER

When the wind force on blades is expressed by F_1 and that on an unit height of a tower is expressed by f_2, the base shear and the base overturning moment can be given by Eq.(1) and Eq.(2) as shown in Fig.(1).

$$F = F_1 + \int_0^H f_2(z)dz = \frac{1}{2}\rho U_{H'}^2 C_{f_1} A + \int_0^H \frac{1}{2}\rho U(z)^2 C_p D(z)dz \quad (1)$$

$$M = F_1 H' + \int_0^H f_2(z)zdz = \frac{1}{2}\rho U_H^2 C_{f_1} AH' + \int_0^H \frac{1}{2}\rho U(z)^2 C_p D(z)zdz \quad (2)$$

where H is the height from the ground to the center of the hub, ρ is air density, U_H is the mean wind speed at the height, C_{f1} and C_p are the wind force coefficients for the blades and the tower, A is the reference area for the blades, and $D(z)$ is the diameter of the tower. The profile of the wind force on the tower can be assumed to be any function. In Eqs.(1) and (2), that is assumed to the same as the velocity pressure at the height z.

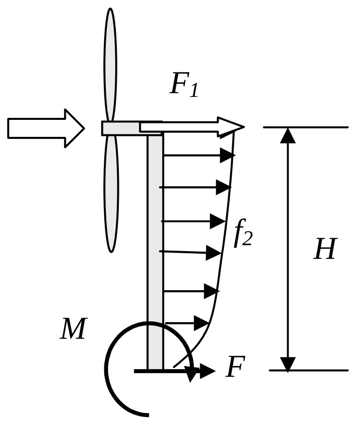

Fig.1 Wind forces on a wind turbine

The wind force coefficients on the blades and the tower can be estimated by solving Eqs.(1) and (2). These equations depend on the following two assumptions. The first assumption is that the wind force on the blades acts on the center of the hub. The other assumption is the profile of the wind force on the tower is being constant at any instant. Both these two assumptions are not strictly true, but are reasonable to estimate the design wind loads as are shown in the following chapter.

3 EXPERIMENTAL RESULTS

3.1 Outline of wind tunnel experiment

The wind tunnel experiments are performed in the boundary layer wind tunnel of Kyoto University of which test section is 2.5m x 2m x 21m. A 1/100 model of the 2.5MW wind turbine was set the turntable located at 16.5m from the windward end of the test section. The height of the tower is 82m and the length of the blade is 44m. The saw-tooth type barrier was set at the windward end, and 6cm x 6cm cubic roughness blocks were arranged on the floor as is shown in Fig.(2). The exponent of the mean wind vertical profile is 0.15 and the turbu-

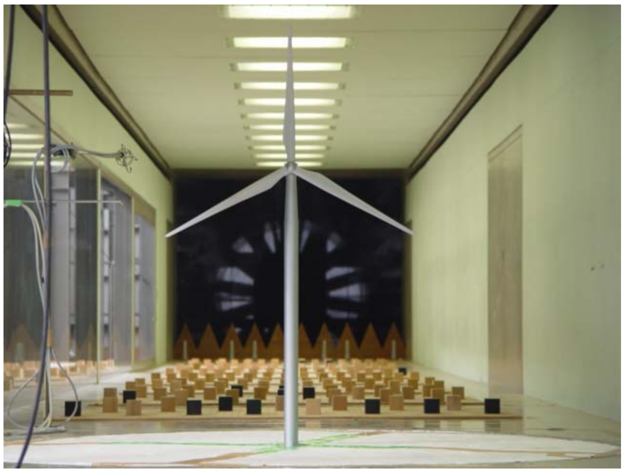
Fig.2 Model in the wind tunnel
Blade pitch is 0 degree, Rotation of the blades is 0

lence intensity is 9 %. Both the pitch and the rotation angles are adjustable to any angle. The model set on a balance to measure the base shear and the overturning moment. The natural frequency is 9.6Hz, the critical damping ratio is 0.6%, and the vibration mode is linear in the system when the model is set.

3.2 Experimental results

Fig.(3) shows the mean drag coefficients for the blades and the tower, when the pitch angle is 0 degree and the rotation angle is 0 degree. The reference area for the drag coefficient for the blades is the projected area of the blades. The drag coefficient for the tower C_p in Eqs.(1) and (2) is converted to C_{f2} to compare directly the magnitude of wind loads which acts on the blades and the tower.

$$C_{f_2} = \Big/ \frac{1}{H}\int_0^H \left(\frac{z}{H}\right)^{\alpha} C_p dz = C_p \big/ (1+\alpha) \qquad (3)$$

where α is the exponent of the mean wind profile.

The drag on the blades is the maximum when the wind direction is 0 degree in the case of the pitch angle is 0 degree, of which drag coefficient is 1.5 times of that for the tower. The drag on the blades decreases gradually until the wind direction is 90 degree when the drag coefficient is 0.25.

Fig.(4) shows the mean drag coefficients when the blades are feathered, of which pitch angle is 90 degree. The drag on the blade is about 20% of that on the non-feathered blades. The maximum drag on the blades occurs when the wind direction is 90 degree, and the drag coefficient is about 0.7, which is lower than the half of the drag coefficient on the non-feathered blade.

Fig.(5) shows the peak drag coefficient when the blades are feathered. The peak drag is about 1.6-1.9 times larger than the mean drag. The instantaneous drags on the blades and the tower do not reach to the maximum simultaneously, so the peak drag coefficient in Fig.(5) is rather conservative.

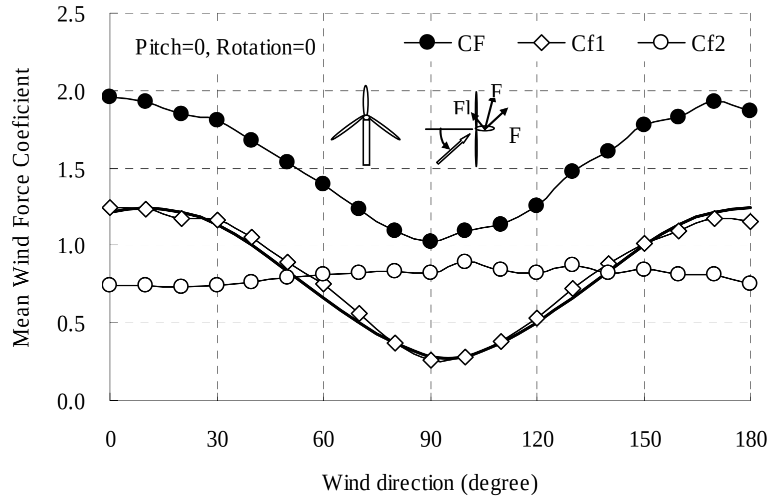

Fig.3 Mean drag coefficient on the blades and the tower.
CF total Cf1 blade Cf2 tower, Pitch angle is 0, Rotation angle is 0

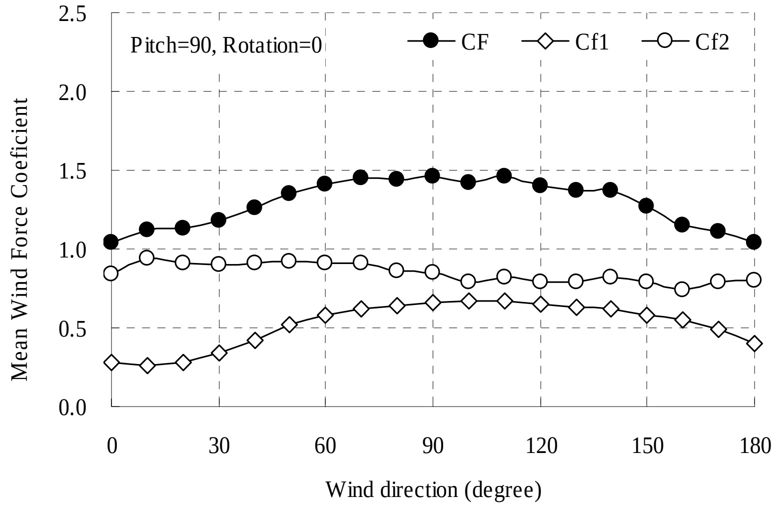

Fig.4 Mean drag coefficient on the blades and the tower.
Pitch angle is 90, Rotation angle is 0

It is more realistic in the structural design to find the peak drag on the blades and the tower when the base overturning moment reaches to the maximum. According to the reanalysis, the peak overturning moment is induced when the drag on the blade takes the maximum. In the case of the wind direction of 100 degree, the peak drag coefficient of the blades and the tower are 1.15 and 1.39 respectively as shown in Fig.(5). However, the peak drag coefficient decreases to 1.15 and 1.11 when the overturning moment reaches to its maximum.

Fig.(6) shows the time histories of the instantaneous drag on the wind turbine, the blades and the tower in the case of the pitch angle is 0 when the wind direction is 0 degree. The fluctuating drag consists with two components. The first is the back ground component. The other is the resonance component. The mean drag on the blade is much larger than that of the tower, but the magnitude of the fluctuation is not so different between the blades and the tower.

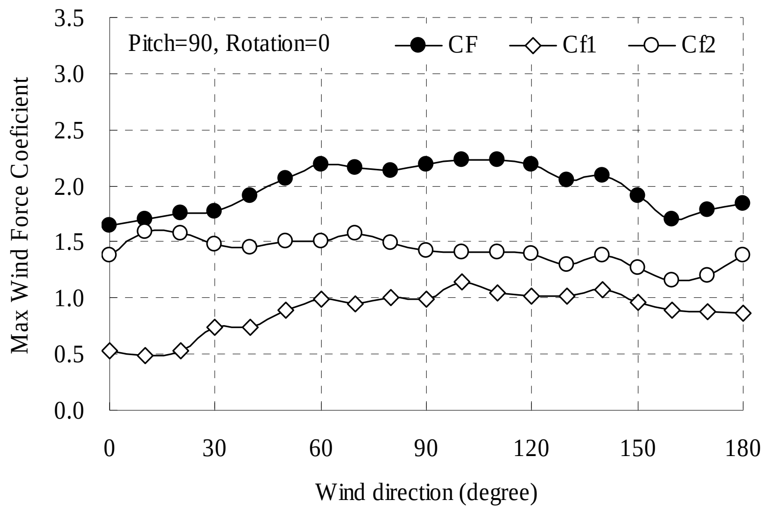

Fig.5 Peak drag coefficient on the blades and the tower

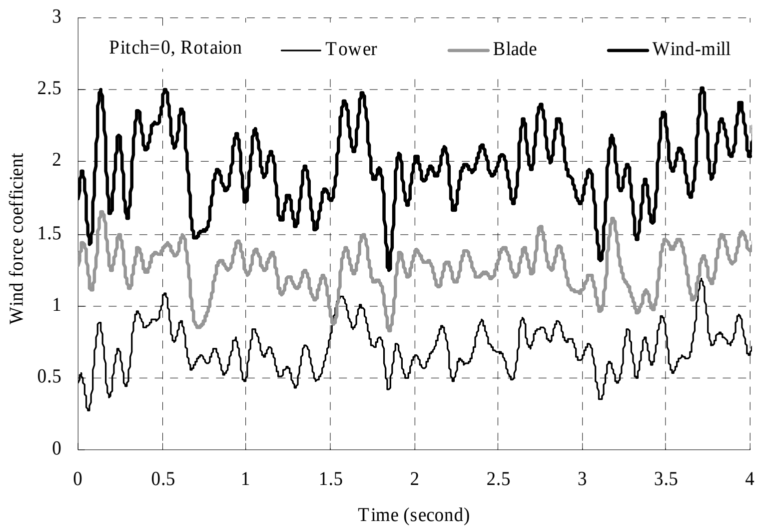

Fig.6 Time history of drag coefficient on the blades and the tower
Pitch=0, Rotation=0, Wind direction=0

4 CONCLUSIONS

The method is proposed to estimate the design wind loads on the blades and the tower from the wind tunnel experimental results obtained by an ordinal base balance technique. From the investigation, the following results are obtained.

(1) The method can estimate the mean and the peak wind loads for the blades and the tower.
(2) The estimated mean and peak wind loads can be consistent with the physical phenomena.

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