

Numerical and Theoretical Study on the Wind Response of Wind Turbine

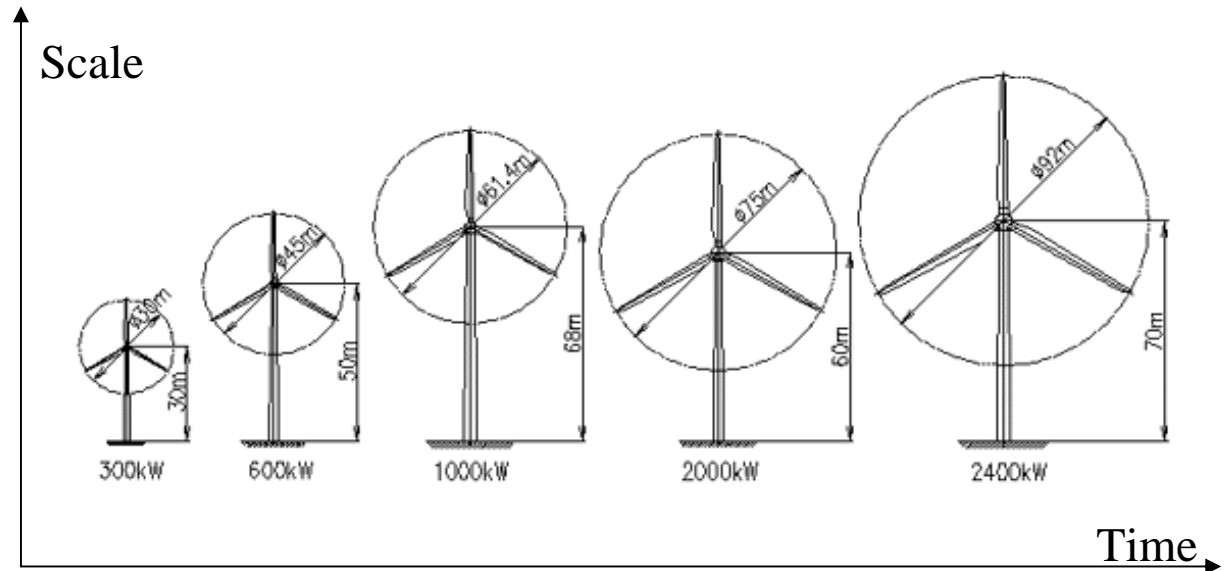
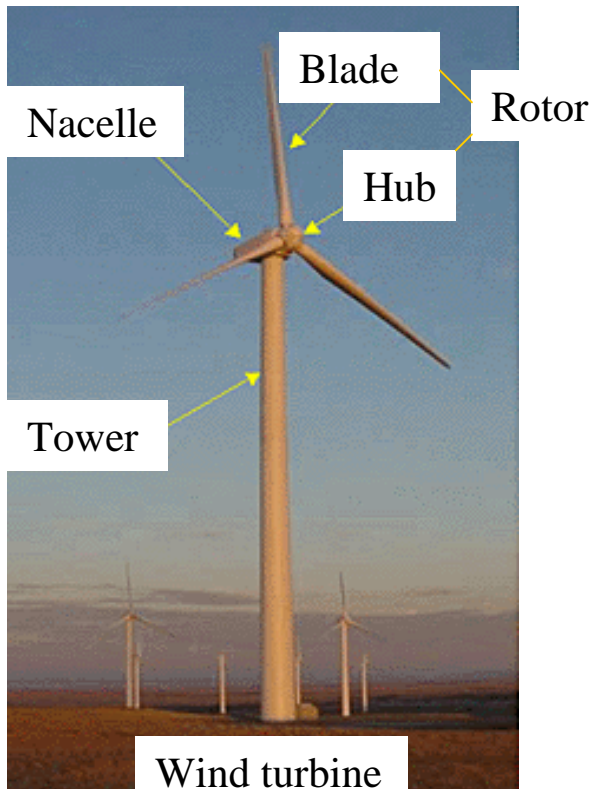
June 11th, 2005

The University of Tokyo

Pham Van Phuc

Wind turbine (WT)

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- Wind turbines are getting bigger
- Turbine rotor size increases
- Hub height increases
- Tower are getting higher

The largest wind turbine

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- 5000kW Wind turbine
 - Manufacturer : Repower (Germany)
 - Rotor diameter : 126m
 - Tower height : 120m

WT transportations

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WT constructions (1)



WT constructions (2)



- Wind energy:
 - pure, clean, and inexhaustible
- Installed turbines (in 2003)
 - All of the world: 40000 turbines.
 - Germany : 12000.
 - USA : 4600
 - Spain : 3550
 - Denmark : 2880
 - Japan : 600
- Target by 2010
 - Japan: 3000 turbines.



Wind farm at Tomamae, Hokaido, northern of Japan

Damages of wind turbine in Japan

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The damage of turbines in the Okinawa Island by typhoon Maemi in 2003

- Many damages of WT tower, blades have been reported consecutively.



- . It is strongly required to enhance the wind resistant design of wind turbines.



Blades broken



Blades broken



Collapsed due to the buckling of the tower

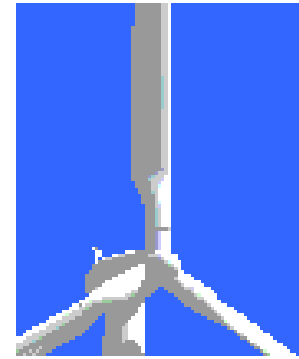


Collapsed due to foundation destruction

Wind turbine design & problems

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- Concepts of WT design (IEC61400-1)
 - Controlled by adjusting the pitch angle of blade (Fig.1) and direction of nacelle (Fig.2)
 - to get maximum wind power during their operations
 - to minimize the wind load during the strong wind



(Fig.1)



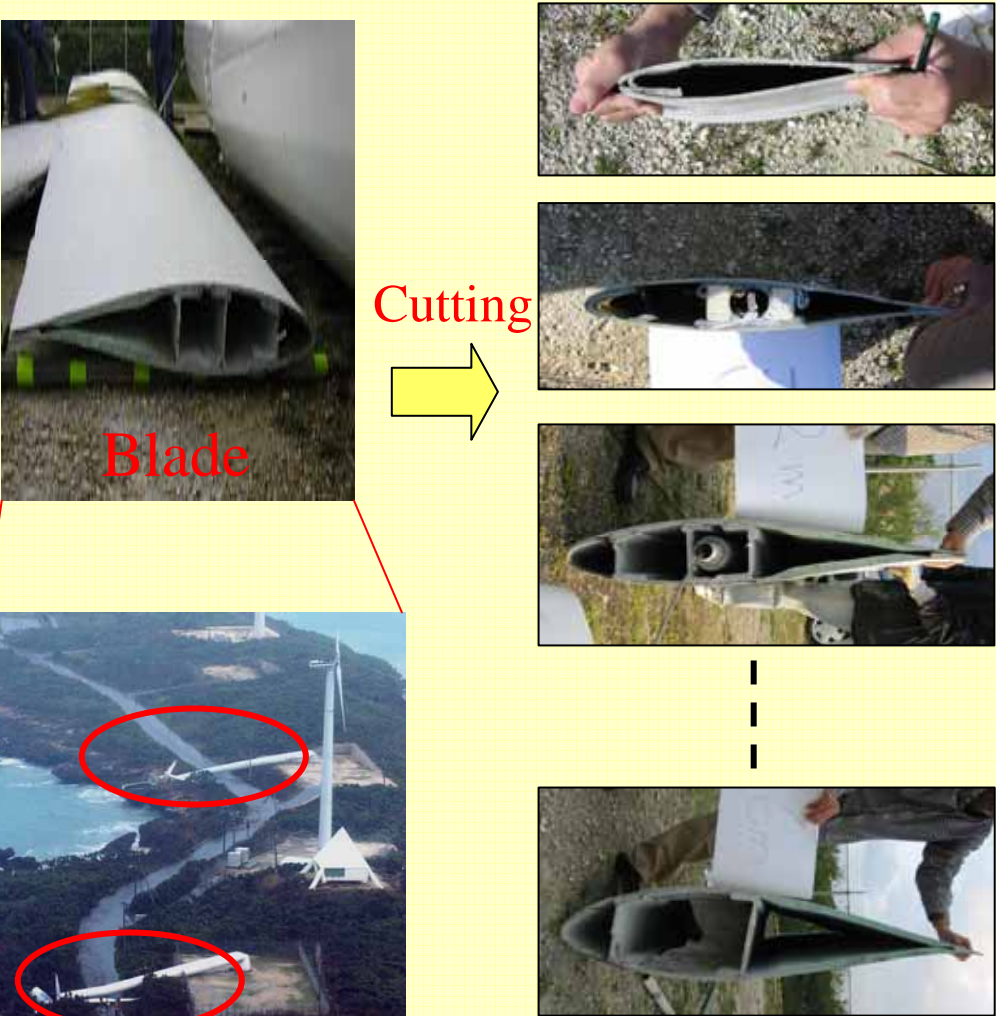
(Fig.2)

- Japan has various types of typhoons and complex mountains
 - Control system becomes ineffective especially during blackout which often occurs during typhoon
 - Control system is insensitive especially in the site with a large turbulence.

Wind resistant design is required to consider the critical wind load

- Carrying out a field investigation and measurement to obtain structural data and characteristics of wind turbine.
- Numerical study
 - Constructing the wind turbine model of beam element. Comparing the eigenfrequencies of analytical model with measured natural frequencies.
 - Developing a FEM code to simulate the wind load. The performance of code is compared with field measurement results.
- Theoretical study
 - Proposing an equivalent static load formulas that can estimate the wind load. The performance of formula is compared with the results from FEM.

Field Investigation

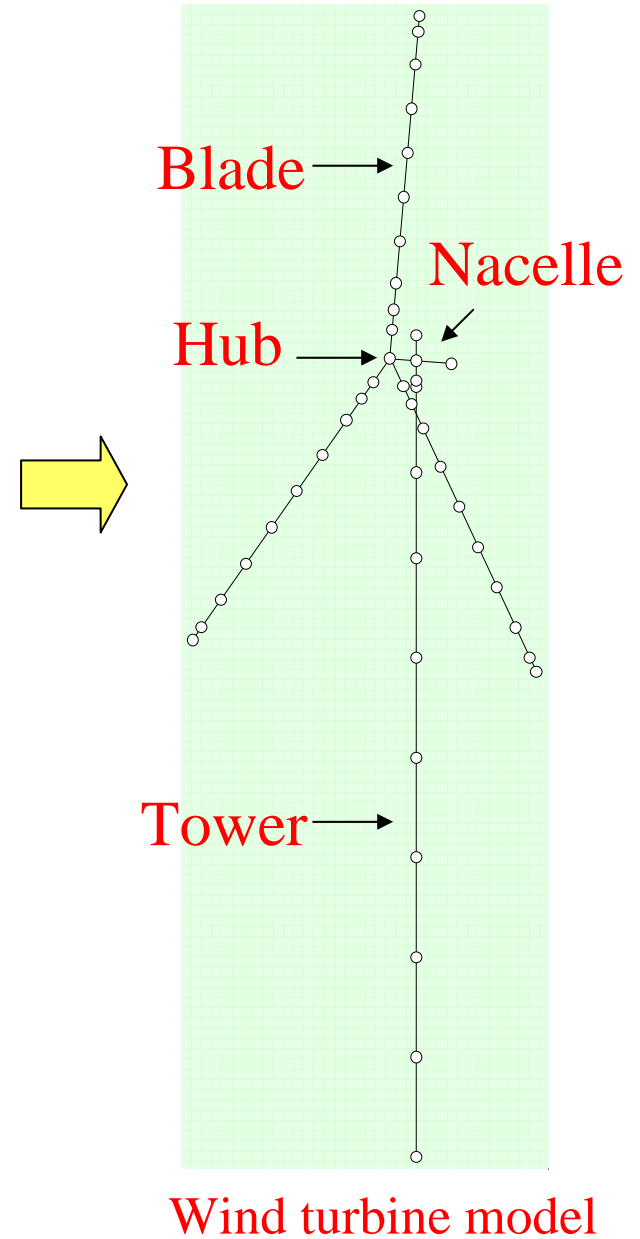


Blade

Cutting

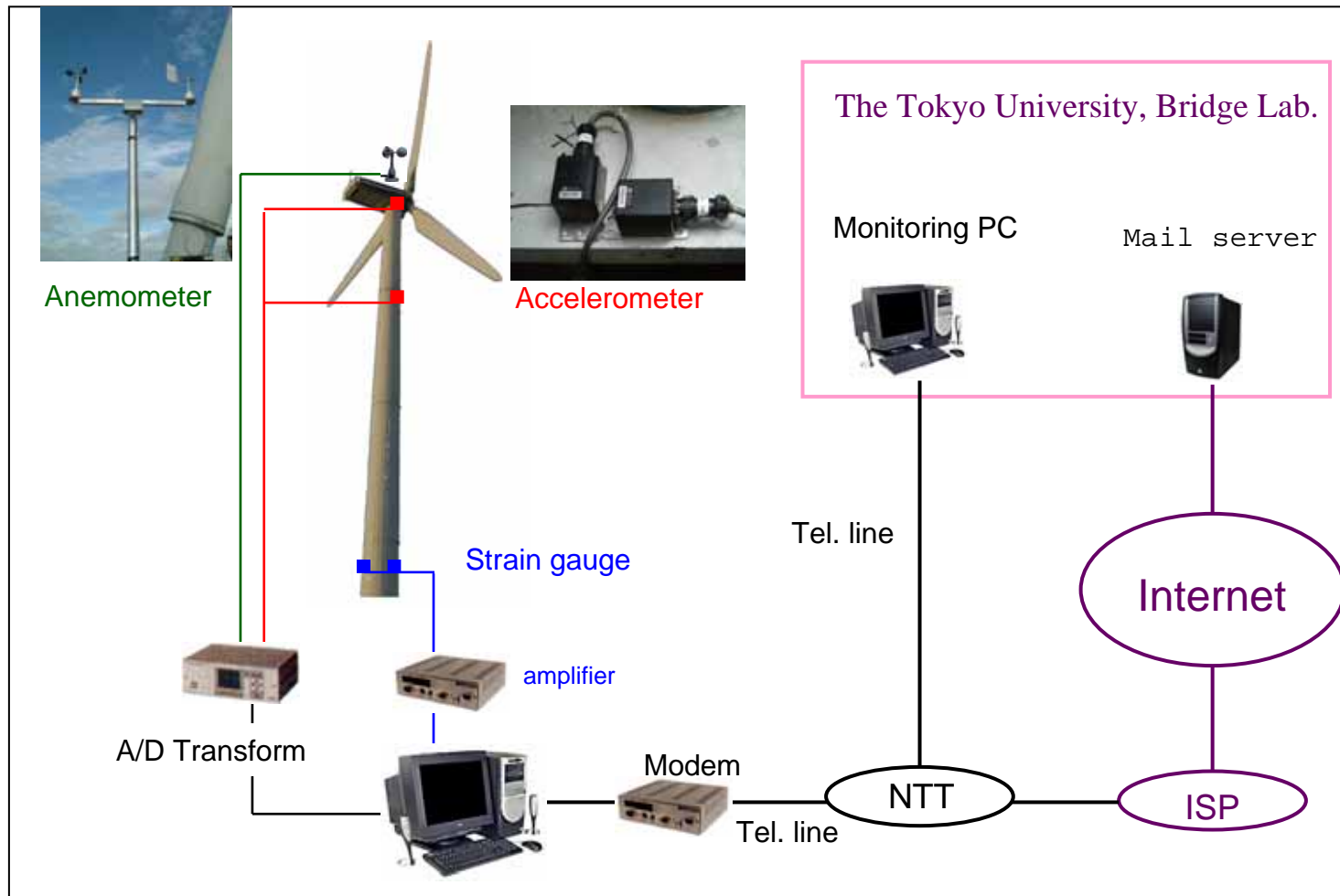
Cut and measure sections

Investigate the collapsed turbines in the Okinawa



Field measurements

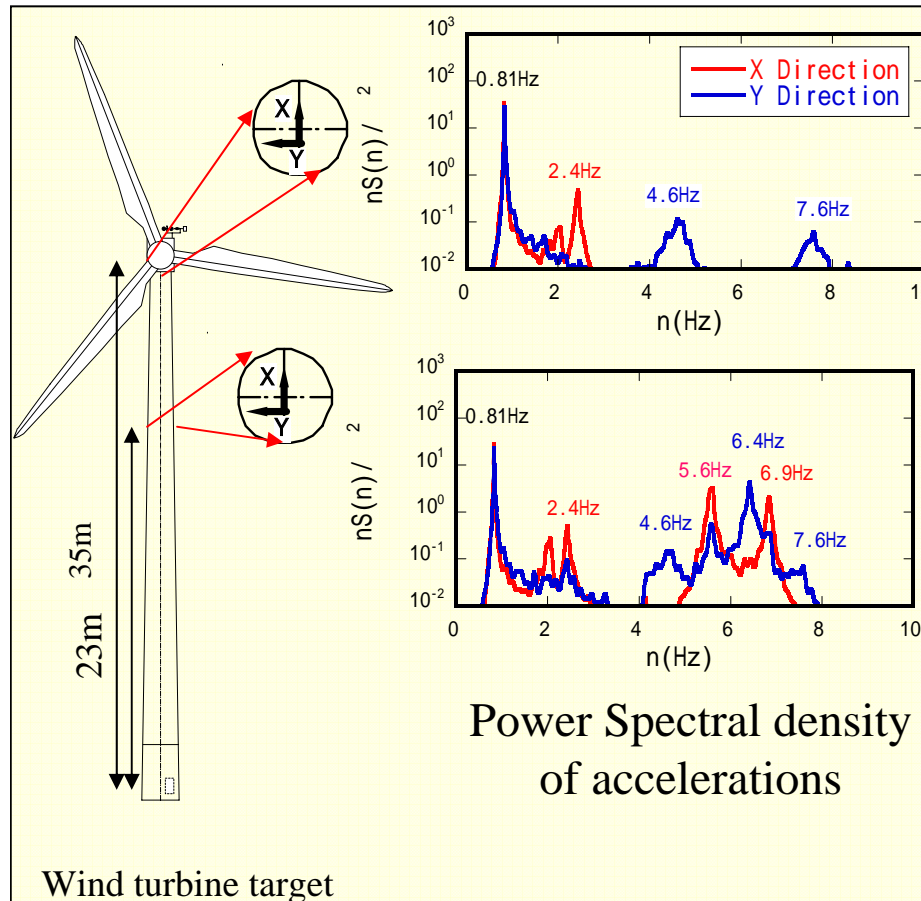
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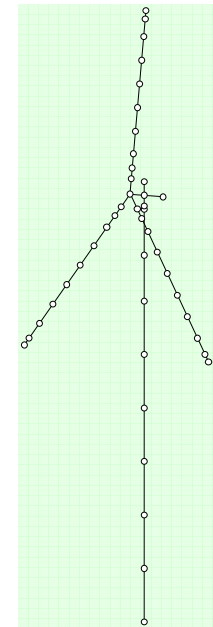
Measure the survived turbine in the Okinawa Island

- Measurement Period : Jan. 16th 2004 ~ Mar. 16th 2004 (2 months)
- Sampling frequency : 20Hz
- Record time : every 10-minute

Wind turbine model contribution



No	Frequencies (Hz)	
	Measurements	WT model
1	0.81 (Y)	0.81 (Y)
2	0.81 (X)	0.81 (X)
3	2.4 (X)	2.4 (X)
4	-	2.5 (X)
5	-	2.6 (X)
6	4.6 (Y)	4.5 (Y)
7	5.6 (Y)	5.3 (Y)
8	5.6 (X)	5.7 (X)
9	6.4 (Y)	6.2 (Y)
10	6.9 (X)	6.3 (X)
11	7.6 (Y)	7.6 (Y)



Eigenvalues analysis for WT model

Good agreement between the eigenfrequencies of WT model and measured natural frequencies of WT

Development of wind response analysis 14/20

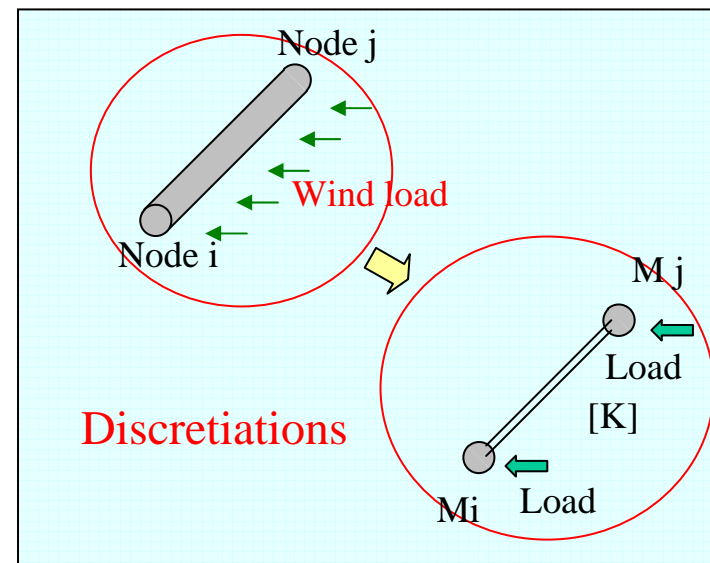
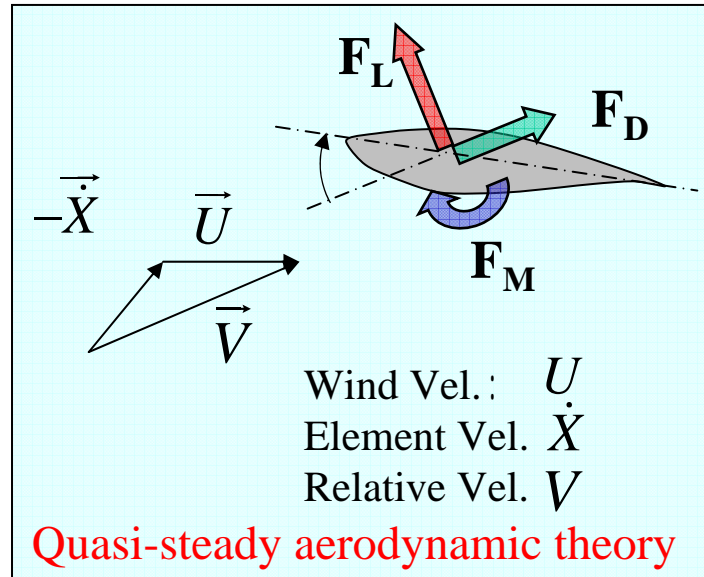
- Aerodynamic force

$$F = 0.5 \rho A C_f(\theta) \times (\vec{U} - \vec{\dot{X}})^2$$

- Motion of equation

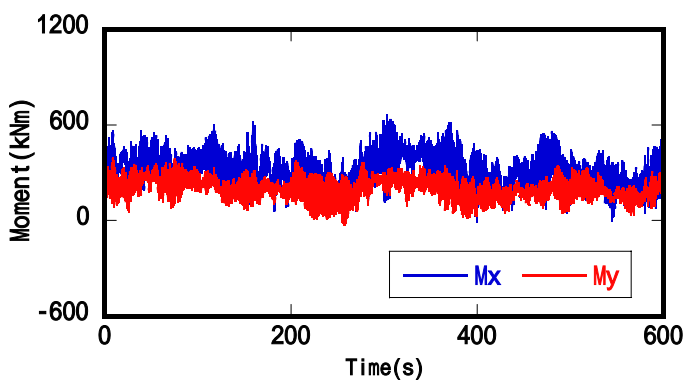
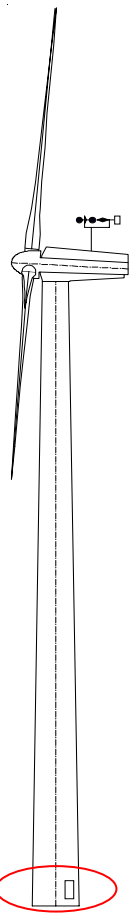
$$M\ddot{X} + C\dot{X} + KX = F$$

- [K]: stiffness matrix
- [M]: Mass matrix
- F: Aerodynamic force vector
- [C]: Rayleigh damping

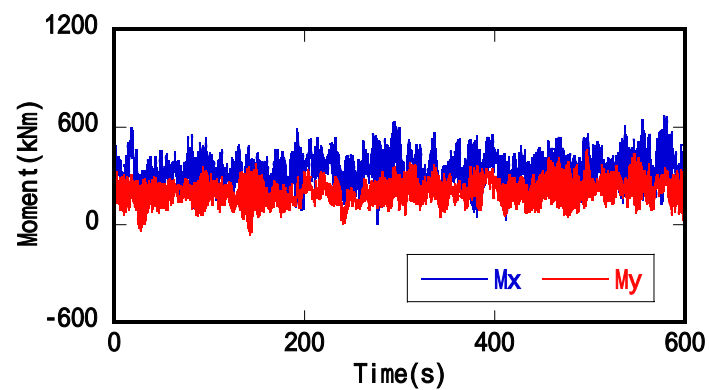


Wind response simulation

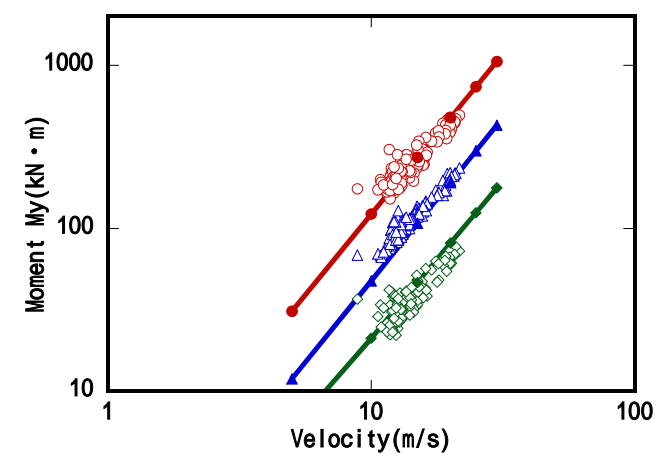
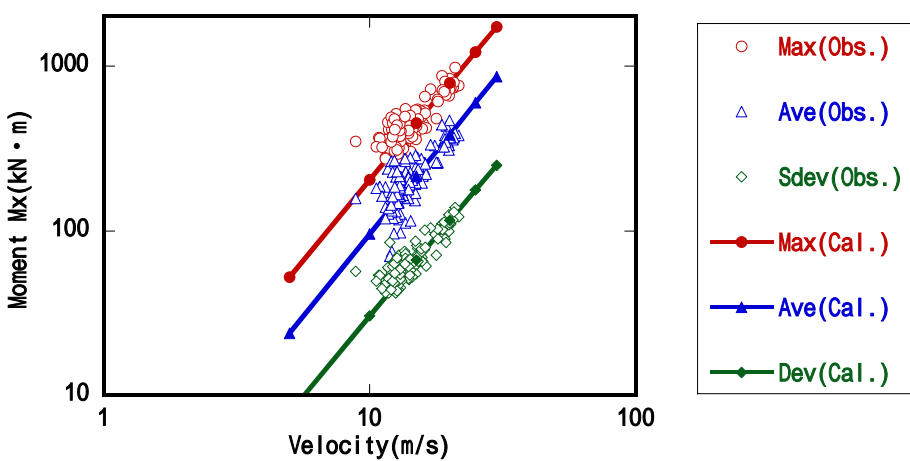
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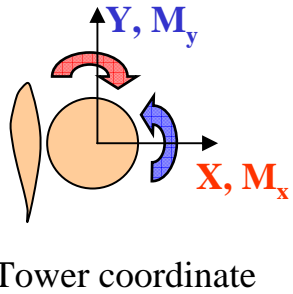
Measured bending moment time series



Simulation bending moment time series



Bending moments against Wind speed



Simulation results show a good agreement with measurement

- Old formula by Building Standard Law of Japan

$$M_{\max} = \bar{M} \times G_f$$

(Mean \times Gust effect coef.)

- G_f is constant

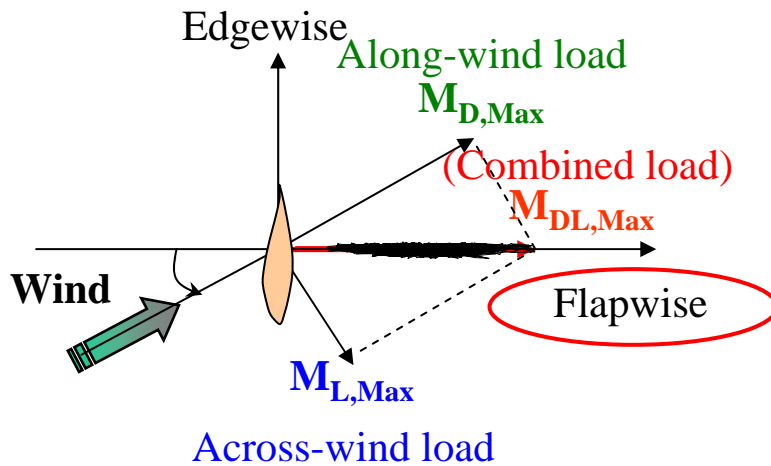
- Proposed formula

- Wind loads of along-wind direction and across-wind direction

$$M_{\max} = \bar{M} \times G_f(n, \xi, \theta)$$

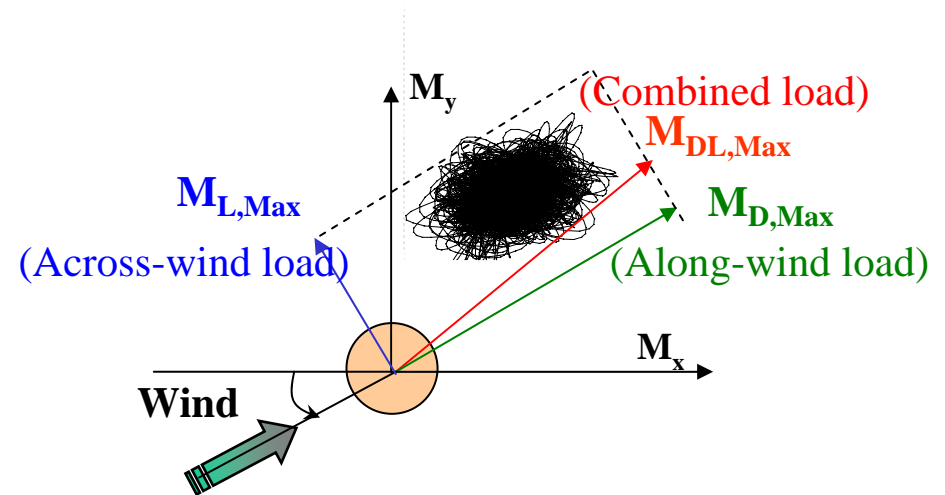
- Considering Freq.(n), Damping() to present the characteristic of wind load on WT. Where : wind direction

- Blade case
 - Vibrating only in flapwise



$$M_{DL,Max}(\theta) = \sqrt{M_{D,Max}^2 + M_{L,Max}^2}$$

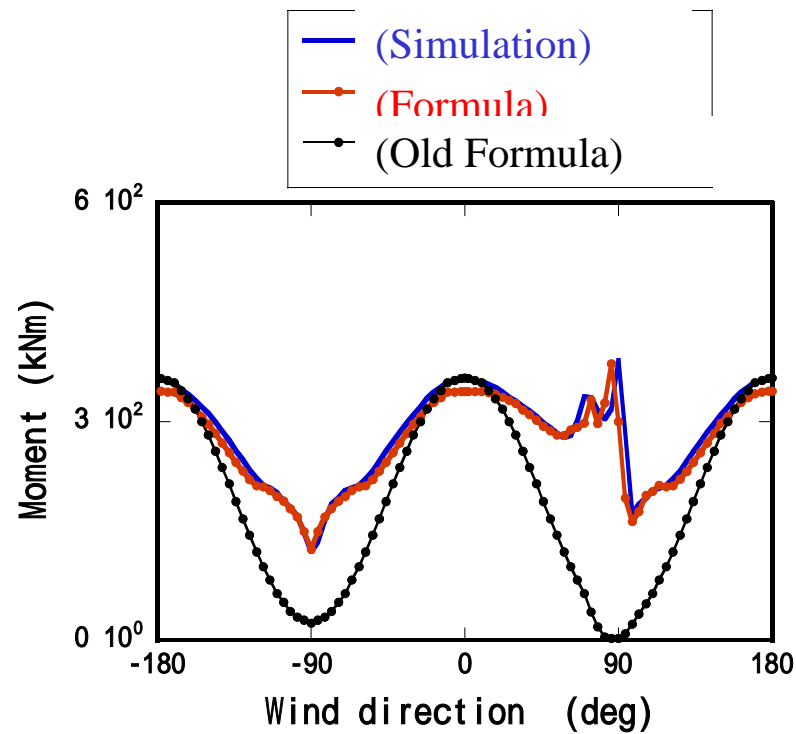
- Tower case



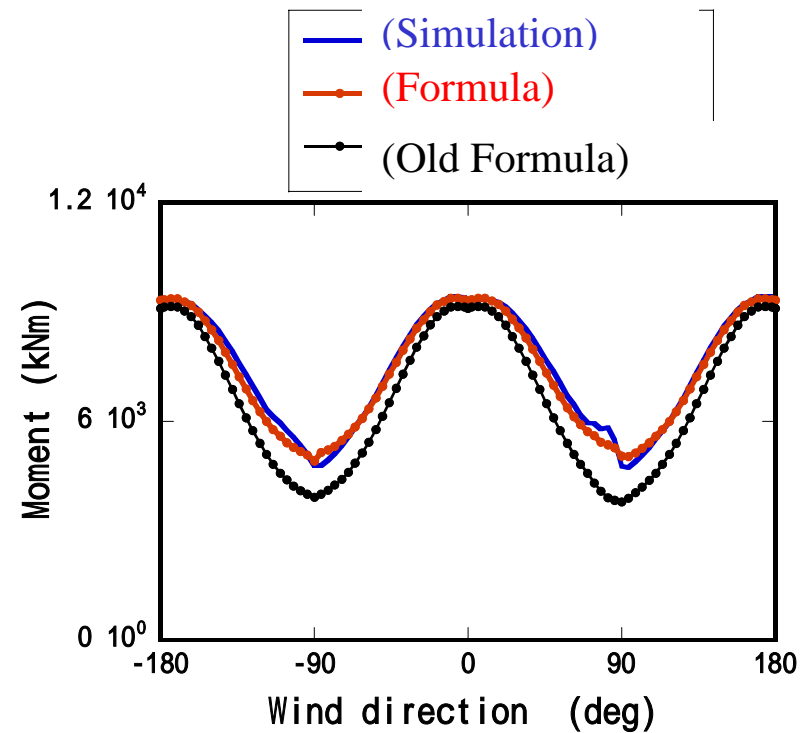
$$M_{DL,Max}(\theta) = \text{Max} \left(\sqrt{M_{D,Max}^2 + (M_{L,Mean} + \sigma_L)^2}, \sqrt{M_{L,Max}^2 + (\bar{M}_{D,Mean} + \sigma_D)^2} \right)$$

The Results of the Proposed equivalent static load 18/20

- Blade case



- Tower case



Proposed formula results show a good agreement with simulation results

The interaction among typical criteria of Japan

- Complex terrain criteria
- Seismic criteria

to determine the relative importance of each aspect and to further assess structural optimization of wind turbine in Japan.

Thank you!