# Loads and Modal Analysis of Pile of Wind Turbine


Wang Wei [1] , Zhang Liang[2] and Sun Liping[3]

[1] Deepwater Engineering Research Center, Harbin Engineering University, Room701, Ship&Ocean Building, No.145 Nantong Street, Harbin, China, 150001
E-mail: **mimal@126.com**

[2] Deepwater Engineering Research Center, Harbin Engineering University, Room702, Ship&Ocean Building, No.145 Nantong Street, Harbin, China, 150001
E-mail: **zhangliang@hrbeu.edu.cn**

[3] Deepwater Engineering Research Center, Harbin Engineering University, Room703, Ship&Ocean Building, No.145 Nantong Street, Harbin, China, 150001
E-mail: **heu102sun@gmail.com**



## Abstract

With the development of renewable energy, wind energy becomes the focus of investigation. At present, many developed countries have built wind tower from land to offshore for usage of more energy resources. In the present paper, expressions of wave, current and ice loads of offshore are investigated, which systematically elucidate the function of the loads. In order to avoid resonance vibration, the modal of the wind turbine and its pile on offshore is analyzed. This paper may provide information for further analysis of renewable energy, especially of wind turbine tower.



**Keywords:** renewable energy, wind energy, pile, modal analysis


## Introduction

Wind has certain advantages over other renewable energy resources. Wind power involves no combustion, so there are no issues related to emissions and air quality[1].

In the past decade, on-land wind power generation has grown significantly and several countries have considerable plans for future expansion. However, on-land turbines are associated with visual impacts on the landscape, noise impacts, impacts on birdlife and other types of impacts on the ecological environment. These impacts make it increasingly difficult to find suitable and acceptable sites for future development. Energy planners have consequently shifted their focus to the vast offshore wind resources. However, even though the offshore location of wind turbines eliminates noise nuisances, visual disamenity is still an issue[2-5].

The energy planner's choice to develop on-land or offshore is, among other things, dependent on the public's acceptance of offshore compared to on-land wind power generation. Though discussions concerning the impacts of wind power have taken place simultaneously with its development, attitudes towards on-land and offshore wind power have not been jointly and systematically analyzed. Energy planners may therefore have insufficient information regarding attitudes in order to efficiently determine the extent to which future wind development should be located on-land or off-shore. There is therefore a real need for more scientific information concerning attitudes towards wind power development[2, 6-8].

In this paper, when a wind turbine tower and its pile are working at offshore, environmental loads are given as below. At the same time, a modal analysis is carried on and the corresponding modes are show in figures.

## Nomenclature

$F_r$ =resistant force

$F_i$ = inertia force

$A$ = object's project area in the coming flow direction （$m^2$）

$V$ = object's unit volume

$\rho$ = object's density

$U$ = velocity of flow mass point

$\dot{U}$ = accelerated velocity of flow mass point

$C_d$ =drag coefficient

$C_m$ =inertia coefficient

$I$ =embedded coefficient

$m$ =pile shape factor

$k$ =contact factor of pile and ice

$\sigma_c$ =the compressive ultimate strength of ice block sample

$d$ =pile diameter

$t$ =the calculated thickness of ice

$T_{0,1}$ =period of ice

$L$ =damage length of ice

$U_{ice}$ =drift velocity of ice

$E$ =modulus of ice

$\nu$ =Poisson ratio of ice

$\gamma_W$ =gravity of water

## 1 Loads

If a wind turbine tower and its pile are on offshore, loads will be different from those on land. Wave, current and ice loads must be considered.

In this section, wave, current and ice loads are analyzed, and the corresponding expressions are given.

### 1.1 Wave Load

Firstly, Morison equations are applied to solve wave load. Morison equations are shown as follows,

$$dF = dF_r + dF_i \, , \tag{1}$$

$$dF_r = \frac{1}{2}\rho C_d A|U|U \, , \tag{2}$$

$$dF_i = \rho C_m V\dot{U} \, , \tag{3}$$

$$F = \int dF \cdot \tag{4}$$

Morison equations consider the velocity and accelerated speed of water particle, which depend on the speed power. The analytic expression of Morison equations is obtained by using theory of linear wave speed power. The analytic expression is

$$F = \frac{-\rho C_m a\omega^2 \pi D^2}{4k}\sin\omega t\left(e^{k\zeta} - e^{-kh}\right) + \frac{\rho D C_d \omega^2 a^2 cos\omega t\,|cos\omega t|}{4k}\left(e^{2k\zeta} - e^{-2kh}\right) . \tag{5}$$

$F$ is the function of time. When $h \to \infty, \zeta \to 0$ , the analytic expression of $F$ is

$$\begin{aligned} F &= \frac{-\rho C_m a\omega^2 \pi D^2}{4k}\sin\omega t + \frac{\rho D C_d \omega^2 a^2 \cos\omega t\,|\cos\omega t|}{4k} \\ &= A_1 \sin\omega t + A_2 \cos\omega t\,|\cos\omega t| \end{aligned} \tag{6}$$

When $\cos\omega t \ge 0$ , the derivative of $F$ is $A_1\omega\cos\omega t - 2A_2\omega\cos\omega t \cdot \sin\omega t = 0$ . In order to make the two sides of equation are equal, there exist two conditions.

(1) $\cos\omega t = 0$ , $\omega t = \frac{\pi}{2}, \frac{3\pi}{2} \cdots$

$$\begin{aligned} F_{max} = F_m &= \frac{-\rho C_m a\omega^2 \pi D^2}{4k} sin\omega t \\ &= \frac{\pm\rho C_m a\omega^2 \pi D^2}{4k} \end{aligned} \, , \tag{7}$$

(2) $A_1 - 2A_2 \sin\omega t = 0$ , $\sin\omega t = \frac{A_1}{2A_2} = \frac{C_m \pi D}{2C_d a}$,

Because $|\sin\omega t| \le 1$, then $\frac{C_m \pi D}{2C_d a} \le 1$ .

The extreme value of $F$ is depend on $C_d, C_m$ in condition (2). In theory, $F$ has two extreme values, the largest one is adopted.

### 1.2 Current Load

The equation of single current is

$$F = \frac{1}{2}\rho C_d A U|U| \tag{8}$$

Action of single current is the simplest condition. Sometimes, wave and current will act together. This will be more difficult. If it happens, the total velocity consists of water particle and current velocities. Then the force can be calculated.

### 1.3 ice load

There are static and dynamic two kinds of ice loads.

Firstly, static ice load is analyzed. Korzhavin-Afanasev equation is used to calculate static ice load. This equation can be express as

$$F_s = \text{Im}\, kdt\sigma_c \, . \tag{9}$$

Using this equation can estimate ice load, but the exact calculation should use dynamic ice load.

Dynamic ice load is calculated according to OFFSHORE STANDARD DET NORSKE VERITAS DNV-OS-J101 and DESIGN OF OFFSHORE WIND TURBINE STRUCTURES. The period of ice function can be expressed as

$$T_{0,1} = L / U_{ice} \, . \tag{10}$$

According to DNV J101, dynamic ice load is

$$F = \begin{cases} \frac{8F_0}{7T_{0.1}}\tau + 0.2F & 0 < \tau < 0.7T_{0.1} \\ F_0 - \frac{7F_0}{T_{0.1}}(\tau - 0.7T_{0.1}) & 0.7T_{0.1} < \tau < 0.8T_{0.1} \\ 0.3F_0 - \frac{F_0}{2T_{0.1}}(\tau - 0.8T_{0.1}) & 0.8T_{0.1} < \tau < T_{0.1} \end{cases} \, , \tag{11}$$

where $L$ is damage length of ice, it is

$$L = \left(\frac{\frac{1}{2} E t^3}{12\gamma_W (1 - v^2)}\right)^{0.25} . \tag{12}$$

Wave, current and ice loads are the most representative loads for wind tower and its pile. Only these loads are determined, further analysis can be carried on.

## 2 Modal analysis

In this section, in order to avoid resonance vibration, the modal of a structure is analyzed. This structure consists of wind turbine and its pile. The height of the tower support is 52 meters, and the pile is 40 meters. The finite element model is shown in Figure 1.

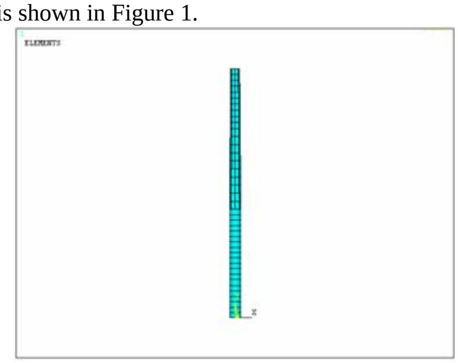


**Figure 1:** The finite element model of wind tower and its pile

Modal analysis is analyzed by this finite element model. According to the modal analysis, there are six frequencies and the corresponding modes are shown in Figure 2 to Figure 7.

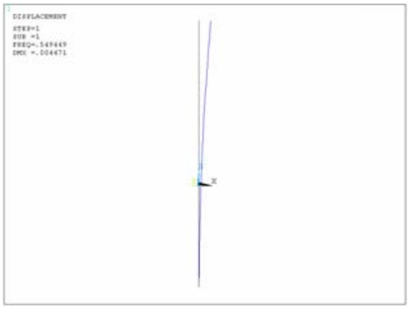

**Figure 2:** The first order of wind turbine and its monopile

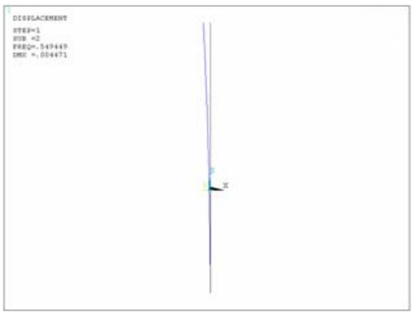

**Figure 3:** The second order of wind turbine and its monopile

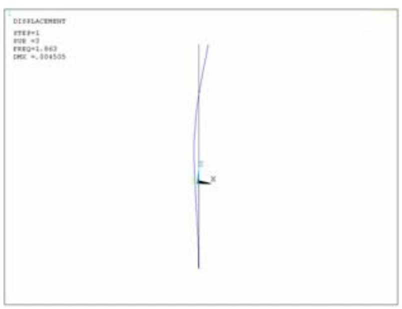

**Figure 4:** The third order of wind turbine and its monopile

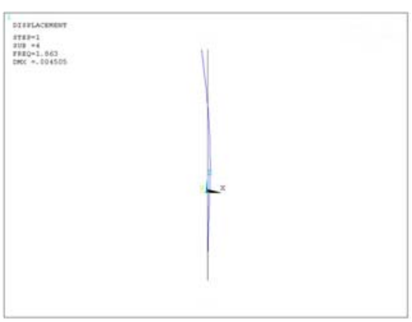

**Figure 5:** The fourth order of wind turbine and its monopile

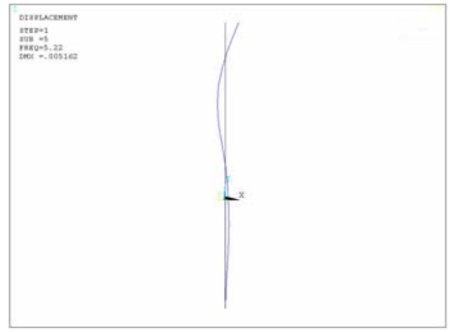

**Figure 6:** The fifth order of wind turbine and its monopile

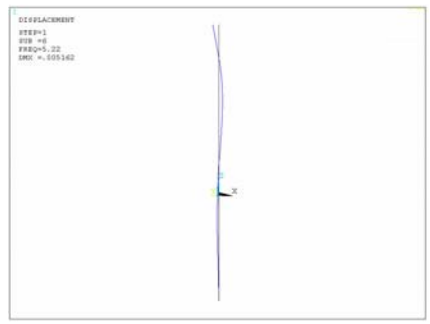

**Figure 7:** The sixth order of wind turbine and its monopile

Because the structure is symmetric, the modes are symmetric too. The corresponding frequencies values are shown in the figures.

## 3 Conclusions

In the present paper, the expressions of wave, current and ice loads are given. These may help choosing the right method to calculation. On the other hand, in order to avoid resonance vibration, the modal of the wind turbine and its pile on offshore is analyzed.

This paper may provide information for further analysis of renewable energy, especially of wind turbine tower.


## Acknowledgements

The authors would like to acknowledge the support of Fundamental of “111 project” (Grant No.B07019) from state Administration of Foreign Experts Affairs of China and Ministry of Education of China. Contributions to aspects of this work were made by other participants in our team especially to Zhao Jing.


## References


[1] James Reinertsen and Martha Hewett. A practical guide to wind energy development for municipal utilities. *Center for Energy and Environment 211 North First Street,Suite 455 Minneapolis,MN 55401.* 1-3, 1999.

[2] P. Flores, A. Tapia, G. Tapia. Application of a control algorithm for wind speed prediction and active power generation. *Renewable energy.* 30:523-536, 2005

[3] Jacob Ladenburg. Attitudes towards on-land and offshore wind power development in Denmark; choice of development strategy. *Renewable energy.* doi:10. 1016 /j. renene. 2007.01.011

[4] T.T. Cockerilla, M. K.uhn， G.J.W. van Bussel, W. Bierboomsc, R. Harrison. Combined technical and economic evaluation of the Northern European offshore wind resource. *Journal of Wind Engineering and Industrial Aerodynamics.* 89:689-711, 2001.

[5] A-Hamid Marafia, Hamdy A. Ashour. Economics of off-shore/on-shore wind energy systems in Qatar. *Renewable energy.* 28:1953-1963, 2003.

[6] G. Li. Feasibility of large scale offshore wind power for Hong Kong --a preliminary study. *Renewable energy*. 21:387-402, 2000.

[7] G. Gaudiosi. Offshore wind energy prospects. *Renewable energy*. 16:828-834, 1999.

[8] Ian D. Bishop, David R. Miller. Visual assessment of off-shore wind turbines: The influence of distance, contrast, movement and social variables. *Renewable energy*. 32:814-831, 2007