Design of Offshore Wind Turbine Foundation Monitoring System Based on Excel

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***Abstract*—Taking Excel as the development platform, one offshore wind turbine foundation monitoring system software is developed merging two excellent analysis softwares, namely FlexPDE expert in multi-physics coupling simulation and ANSYS expert in structural analysis and display features. They are integrated together, the influence of seabed instability on the pile response could be considered, so the pile response simulation is more close to the actual condition. By using of such a simple software, Donghai-bridge offshore wind farm soil condition is evaluated, this example shows that this monitoring software is practical, could be used in the offshore wind turbine monitoring.**

***Keywords*—offshore wind farm; seabed instability; Biot consolidation theory; numerical result; Mohr-Coulomb criterion**

I. INTRODUCTION

Usually, the onshore wind farm development would be restricted by such problems as land resource limited, public visual disturbance, noise pollution and land landscape destruction etc., whereas, the offshore wind farm does not occupy the land, would not be confined by the environmental restriction, furthermore, the average wind velocity at sea is higher, the wind speed 10km off the shore is 25% higher than that along the shore [1]. Nonetheless, compared with the onshore wind turbine, the offshore wind turbine must be firmly fixed on the sea floor, the support structure must be more stable, besides, the special vessels and equipments are required in the construction and maintenance work, therefore, the investment on the offshore wind farm would be much higher than onshore, generally 2-3 times than that on the onshore. Thereinto, the foundation installation cost accounts for 30% of the total cost [2]. Hence, for the moment how to reduce the foundation installation cost is one of main challenges confronted in the offshore wind farm. In addition, the operation and maintenance expense of the offshore wind turbine is also too high, innovative measures are required to reduce the generating cost. But even more important, the offshore wind turbine structure is located in the severe environment, stands against wind, ocean wave, floating ice, ocean current, tide and earthquake etc, besides, it would bear the fatigue accumulation induced by environmental corrosion, antifouling coating, maintenance and repair ship collision, material degradation, member drawbacks and mechanical damage etc. A good many adverse factors would make the structural resistance capability loss. If the offshore wind turbine structure is damaged, it will bring about not only economic loss, but serious social impact. Accordingly, applying the effective reliable real time health monitoring on the offshore wind turbine structure is of importance to determine the damage location and extent, to estimate the residual life and to appropriately arrange the maintenance.

Unfortunately, up to now there have been no integrative monitoring software exclusively used in the offshore wind turbine foundation. Thereby, this article takes Excel as the development platform, works out one simple practical software. It merges two excellent analysis software——FlexPDE and ANSYS, the former is expert in multi-physics coupling simulation, while the latter is expert in structural analysis and display features, moreover, they are integrated together, the influence of seabed instability on the pile response could be considered, so the pile response simulation is more close to the actual condition.

II. Design principle of monitoring system

A. Design concept of monitoring system

The offshore wind turbine structural system is composed of rotor, hub, tower, machine and power transmission system, rotation and safety system, foundation and underlying soil[2]. Obviously, the foundation and the underlying soil are of great importance to the structural safety. In the marine environment, when the wave is propagating over the seabed, it will generate prominent dynamical pressure, which will make the pore water pressure and the effective stress change. The excess pore pressure will increase while the vertical effective stress will decrease; then, part of seabed will be instable, even liquefied. Once the soil is liquefied, the earth grain may be carried off by the bottom ocean current as fluid, or be transferred along with the mass migration induced by the wave action. In the ocean environment, the seabed instability phenomena often occur, it generally is appears as that the soil is displaced, and the limiting forms are divided into shear failure, liquefaction and scour. When the soil displacement is imposed on the pile, the pile internal force and deformation will increase, up to a certain degree, the pile will be damaged. Therefore, the offshore wind turbine foundation system condition evaluation should cover two-sided contents, namely, the soil condition evaluation and the pile condition evaluation, they are

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interconnected. Based on such a concept, we develop one offshore wind turbine foundation monitoring system software on Excel platform, the software development process is shown in Fig.1, the whole interface is shown in Fig.2. The ocean environment parameters and the geologic parameters could be received from the data collecting instrument, or directly be input, the geologic information could be displayed in the textbook in the lower left corner. In the FlexPDE module, the wave-seabed interaction model could be found based on Biot consolidation model and the left parameters [3,4], it should be noted that the model could be edited by clicking "Edit Source File" button. In the soil evaluation module, it uses the results from the FlexPDE module and Mohr-Coulomb criterion and Okusa liquefaction criterion to evaluate the soil condition [5,6], by clicking this button one whole soil condition evaluation report would be produced, the brief conclusions would be shown in the textbox in the lower right corner. After transferring the soil displacement result to the ANSYS module, the pile response considering the seabed instability influence would be yielded; the pile-soil interaction model could be modified by clicking "Edit Source File" button. Through comparing the pile response with the limit values in codes [7], the pile condition would be evaluated, by clicking "Pile Evaluation" button one whole pile condition evaluation report would be produced, the brief conclusions would be shown in the textbox in the lower right corner.

B. *Solving principle of FlexPDE [8]*

FlexPDE is a fully integrated partial differential equation solver developed by PDE Solution Inc., it can be used to solve the linear and nonlinear partial differential equation (group) . Its basic operating principle is translating the system described by the partial differential equation (group) into one finite element model by use of Galerkin method, the mesh quantity and density of which could be automatically adjusted according to the given error limit. For the nonlinear partial differential equation, FlexPDE employs the modified Newton-Raphson iteration method to solve it. This software is composed of several modules as followed: (1) a script editing module； (2) a symbolic equation analyzer； (3) a mesh generation module； (4) a finite element numerical analysis module； (5) an adaptive mesh refinement procedure; (6) a dynamic timestep control procedure； (7) a graphic output module； (8) a data output module.

C. *Solving principle of ANSYS [9]*

The dynamic control equation for the pile-soil structural system could be given by

$$[M]\{\ddot{u}\}+[C]\{\dot{u}\}+[K]\{u\}=\{F(t)\} \tag{1}$$

where $[M]$, $[C]$ and $[K]$ are the mass matrix, damping matrix and stiffness matrix of the structural system, respectively; $\{\ddot{u}\}$, $\{\dot{u}\}$ and $\{u\}$ are the acceleration, velocity and displacement vector of the node; $\{F(t)\}$ represents the structural load vector. According to the structural element type and the corresponding real constants and material characteristics, ANSYS program will automatically calculate the mass matrix, stiffness matrix and load vector of each element, then assembles these matrices and vectors into the mass matrix $[M]$, stiffness matrix $[K]$ and load vector $\{F(t)\}$ of the whole structure. The pile-soil interaction in the lateral direction is simulated by *p-y* curve, thereinto, *p* represents the lateral soil reaction, *y* represents the relative displacement between the pile and the soil. According to α and β, the damping matrix could be calculated as followed：

$$[C]=\alpha[M]+\beta[K] \tag{2}$$

And then ANSYS will substitute the matrices and load vectors of the whole structure into (1), and work out the dynamic response of each node by use of Newmark difference method, according to the given initial and boundary conditions.

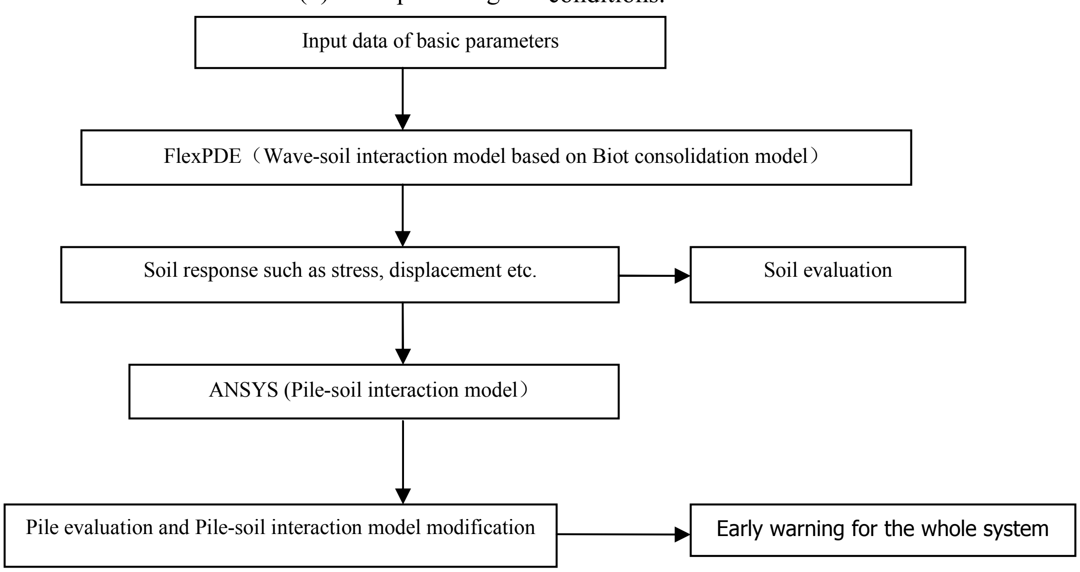

Fig.1 Monitoring system development process

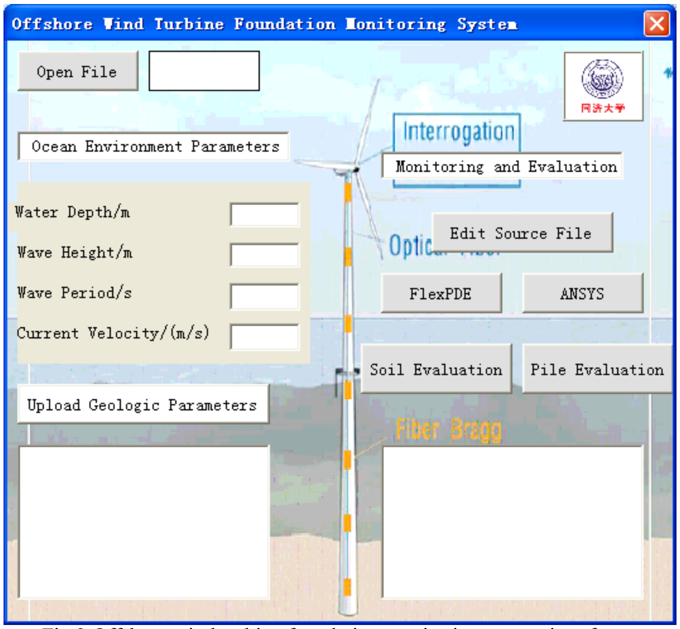

Fig.2 Offshore wind turbine foundation monitoring system interface

III. Example of application

In this article, taking Donghai-bridge offshore wind farm as the background, we use this monitoring system software to evaluate the wind farm site soil condition. Donghai-bridge offshore wind farm is the first one large offshore wind farm in Asia, located at Nanhui offshore waters of shanghai, and the wind turbines are arranged at both sides of Donghai-bridge, the total installed capacity is 100MW, which may generate 2.67 hundred millions kilowatt hours, satisfying the utilization demands of 400 thousands people in Shanghai. The marine environment conditions and geologic conditions could refer to literature [10], we evaluate the soil condition under the breaking wave action (H_b=11.7m) by use of the offshore wind turbine foundation monitoring system software, Fig.3 is the stress angle contour distribution diagram, and Fig.4 is the total effective normal stress distribution diagram along the depth. From Fig.3, it could be observed that for the soil at the same depth the stress angle at the crest is greater than at the trough, so the soil at the crest will firstly occur damage; besides, according to Mohr-Coulomb criterion the soil nearly 4m deep is close to shear failure. At the same time, Fig.4 shows that the soil nearly 4m deep is already liquefied, they are almost identical. The evaluation result is credible.

IV. CONCLUSIONS

Taking Excel as the development platform, one offshore wind turbine foundation monitoring system software is developed, FlexPDE and ANSYS are merged together, so that the influence of seabed instability on the pile response could be considered. And this software could be used to evaluate both of the soil condition and the pile condition, it is one integrative soft ware, simple, open and easy to use, the example shows it can be used in the offshore wind turbine monitoring.

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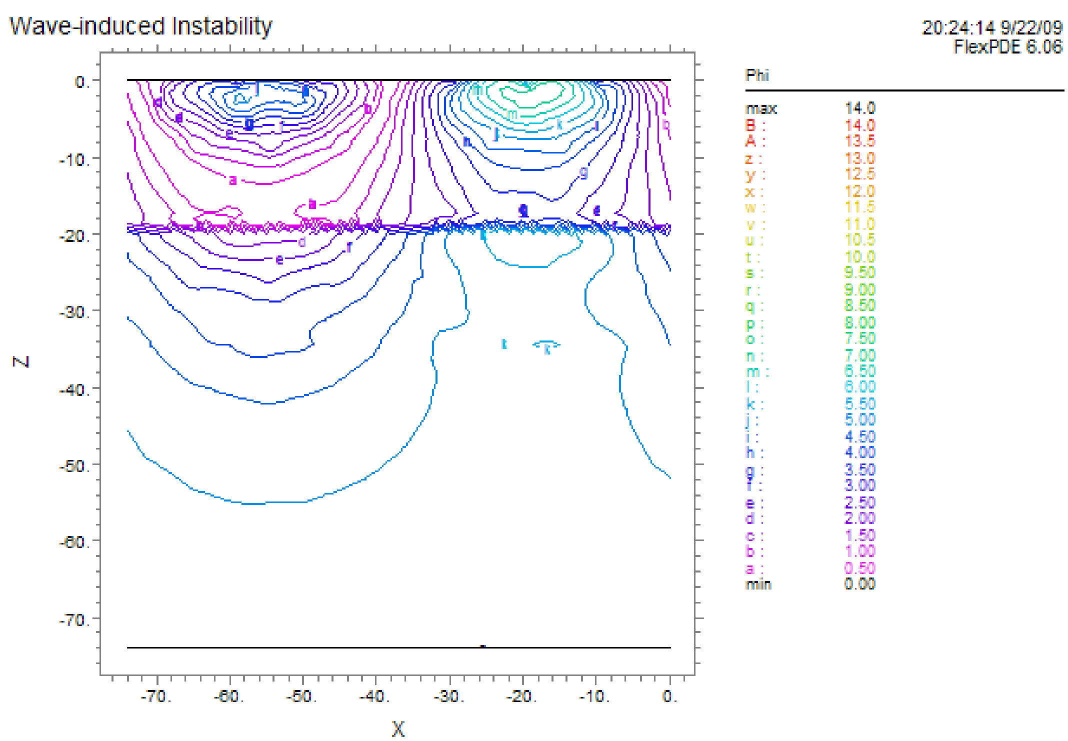

Fig.3 Stress angle contour distribution

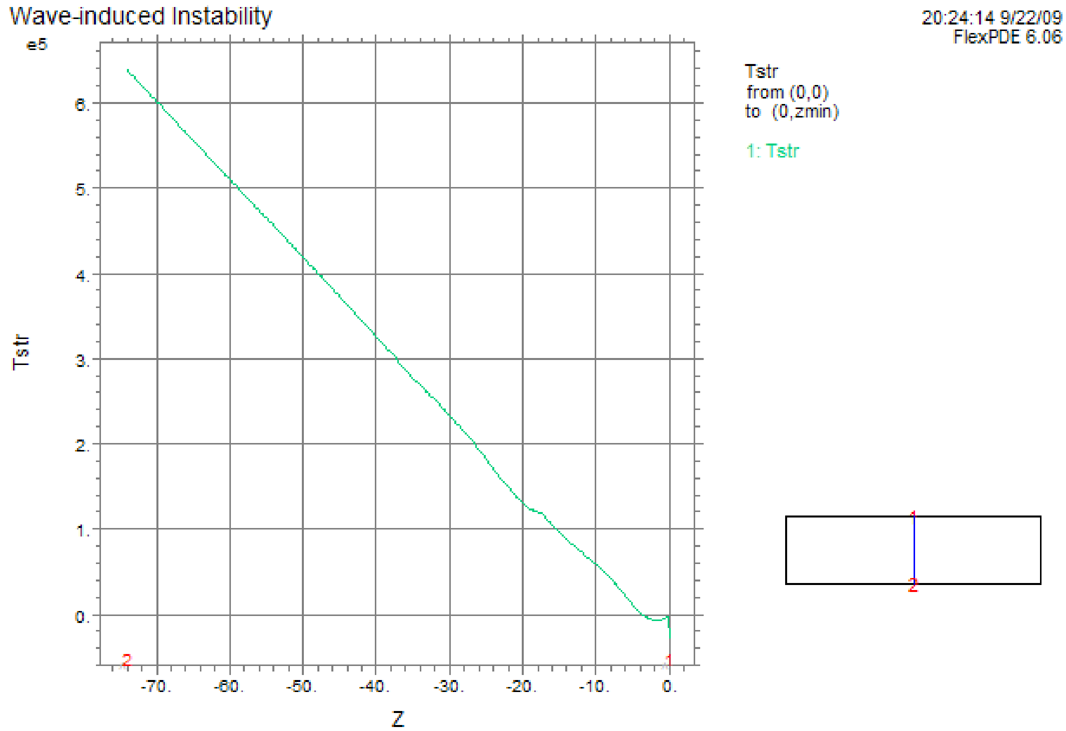

Fig.4 Soil total effective normal stress distribution along the depth

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