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Research on Short-term Ice Cases for Predicting Ice Force on Conical Structure in the Bohai Gulf

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Offshore structures in the Bohai Gulf are often under the threat of sea ice. Due to the fact that the ice environments, such as the ice thickness and tensile strength, often change over the years and in the sea areas, it is better to determine a series of ice cases with the occurrence probability to predict the ice force on the structure in the Bohai Gulf. To calculate the ice force on the structure accounting for the uncertainty of the ice environments, such as the ice thickness and tensile strength, a method for determining the ice case in the Bohai Gulf was proposed, and an element was developed to simulate the sea ice as a user modification of the Finite Element Analysis (FEA) commercial software ABAQUS. At the same time, the Winkler foundation and the failure criterion introduced by Reinicke and Remer were implemented in the element to take into account the bending failure of the sea ice and the influence of the buoyancy force. An open and universal framework for determining the ice cases in the Bohai Gulf has been proposed.

INTRODUCTION

With the rapid development of China's economy, there is a huge need for clean and sustainable energy such as solar and wind power. In recent years, the demand for an offshore wind turbine in the Bohai Gulf located northeast of China has been growing fast. However, the ice conditions in the Bohai Gulf can affect the safety of an offshore wind turbine foundation. To design an offshore wind turbine foundation in the Bohai Gulf, the force caused by the interaction of the ice sheet and structure needs to be assessed.

Over the past decades, researchers have found that the ice force on a conical structure is significantly smaller than the force on a cylindrical structure of similar size. At the same time, many theoretical studies have been performed to predict the ice force on conical structures. Bercha and Danys (1975) presented a theoretical expression to estimate the ice forces on cones. In their study, the ice sheet was idealized as a linear elastic plate on an elastic foundation. The failure of the ice sheet was assumed to be governed by a brittle failure based on the maximum tensile stress failure criterion. Ralston (1980) studied the ice forces on cones on the basis of the plastic upper limit theory of a floating plate. The ice sheet was idealized as an elastic-perfectly plastic plate supported by an elastic-perfectly plastic foundation. In the Recommended Practice published by the American Petroleum Institute (1995), the theories based on elastic beam bending, elastic wedge bending, and plastic plate bending have been presented to predict the ice forces against cones. In recent decades, the numerical simulation has been more and more widely used as computer science has developed. Derradji-Aouat (2005) simulated the ice-structure interaction with a new constitutive model. The typical ice-structure interaction situation, such as the ice sheet acting on the sloping structure and vertical piers, was simulated. Sand and Fransson (2006) simulated the interaction between the ice sheet and conical structures. The ice was treated as an isotropic material and a transverse isotropic material with two different constitutive models, respectively. However, the ice environment parameters, such as the thickness and tension strength, have often changed over the years. Most of the previous research on ice loads did not account for the uncertainty of the ice environment parameters. In recent years, on the basis of the results of the field observations in the Bohai Gulf, the probability distributions of the ice environment parameters have been developed. Ji et al. (2002, 2003) researched the probability distribution of the sea ice fatigue parameters in the JZ20-2 sea area in the Bohai Gulf. Liu et al. (2009) proposed the short-term ice cases with variability of ice thickness and direction for the analysis of the ice-resistant jacket platform in the Bohai Gulf. On the basis of these developments of the ice environment parameters in the Bohai Gulf, it will be possible to predict the ice force on a conical structure in the Bohai Gulf accounting for the uncertainty and variability of the ice parameters.

Due to the fact that the ice environments, such as the ice thickness and tensile strength, often change over the years and in the sea areas, it is better to predict the ice force on the structure with the occurrence probability than to determine it with a specific ice case. Meanwhile, there is little previous work on the probabilistic loads on structures in the Bohai Gulf. Hence, the purpose of this research is to develop a framework to determine the ice case in the Bohai Gulf and to calculate the ice force on the structure accounting for the uncertainty and variability of the ice thickness and tensile strength. The nonlinear finite element simulation was adopted to calculate the ice force on a conical structure. At the same time, the Winkler foundation and the failure criterion introduced by Reinicke and Remer (1978) were implemented in an eight-node hexahedral reduced integral element to take into account the bending failure of the sea ice and the influence of the buoyancy force.

SEA-ICE ELEMENT

In recent years, numerical research has been widely used to simulate the mechanical behavior of composite materials (Xie and Waas, 2006; Liu et al., 2017). In this study, the nonlinear finite element simulation was adopted to calculate the ice force on a conical structure. In order to simulate the ice conveniently, an element was introduced via a user subroutine UEL in ABAQUS. The

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