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Mitigation of Ice-induced Vibrations by Adding Cones

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The dynamic ice force and structure response of vertical and conical structures are discussed based on field measurements in Bohai Bay. It is found that significant ice-induced vibrations can occur on both kinds of structures. Adding a cone can avoid a more intense and harmful steady-state vibration. Full-scale tests have been conducted on a monopod structure before and after adding an ice-breaking cone. The effectiveness of mitigating ice-induced vibrations through adding an ice-breaking cone is evaluated based on test data.

INTRODUCTION

When ice sheets run through fixed offshore structures, the ice-breaking process causes dynamic ice force and induces structural vibrations. Ice-induced vibrations of many structures in cold regions have been observed—for example, oil drilling platforms in Alaska's Cook Inlet (Peyton, 1968; Blenkarn, 1970), lighthouses in Bothnia Bay (Engelbrektson, 1977) and jacket oil platforms in the Bohai Sea (Yue and Bi, 2000).

When ice acts on vertical structures, the resulting ice-crushing failure can produce the largest horizontal load and cause strong steady-state vibration. Because the physical process of ice-crushing failure is very complicated, there have not been a proper mechanical explanation and a practical prediction model for ice-induced vibrations on vertical structures. Steady-state vibrations were observed on the vertical structures in the Bohai Sea, and they threatened the structural performance and production facility. Pipeline fracture and flange loosening took place under steady vibrations, which are the most serious condition induced by ice actions.

Adding ice-breaking cones at the water level is one of the methods to resolve ice-induced vibrations. The concept of adding cones to a vertical structure was first proposed for reducing extreme ice force. The principle is that the ice failure mode on conical structures is flexural failure, instead of crushing failure on vertical structures. The effect of reducing extreme ice force by adding cones was proved by theoretical and experimental models (Wessels and Kato, 1988; Izumiyama et al., 1991). Several ice-resistant structures were designed to be of a conical shape at the water level—for example, piers of the Confederation Bridge in the Southern Gulf of the St. Lawrence (Brown, 1997), offshore wind turbine foundations in Denmark (Määttänen, 1996) and oil platforms in China's Bohai Bay (Yue and Bi, 1998).

However, the effects of ice-induced vibration mitigation by the addition of ice-breaking cones are not yet clear. After ice-breaking cones were first installed on the cylindrical legs of a JZ20-2SW jacket structure in Bohai Bay in 1992, cones have been widely used in the region. Field measurements from a JZ20-2MUQ conical jacket structure show flexural ice failure on the cone, which indicates successful reduction of ice loads. Meanwhile, the ice flexural failure process on conical structures could also produce a dynamic ice load and cause distinct vibrations due to ice actions. At the same time, the adding of ice-breaking cones is not well-received because of the complicated fabrication process, including the risk of getting damaged by vessels, the higher loads caused by waves and ice ridges, etc.

It is impossible to compare ice-induced vibrations of a vertical structure to a conical structure by theoretical methods, because the dynamic ice load on vertical and conical structures are not yet completely understood. A practical method is to compare the field measured vibrations, and the vibrations of the same structure with and without a cone would be a good choice.

The JZ9-3E jacket platform was originally a single-leg cylindrical structure. Steady-state vibrations were observed during its first winter in service. An ice-breaking cone was added to mitigate the intense vibrations. Full-scale tests were conducted on this monopod structure before and after the addition of the ice-breaking cone.

This paper illustrates the dynamic ice load and ice-induced vibrations on vertical and conical structures. Field measurements of vibrations at JZ9-3E before and after addition of the ice-breaking cone are compared, and the results show the ice-breaking cone successfully mitigates ice-induced steady vibrations.

ICE-INDUCED VIBRATIONS ON VERTICAL STRUCTURES

Ice-crushing failure on vertical structures is dominant and complicated, as shown in Fig. 1. A theory-based dynamic ice force model on vertical structures is not yet available. Many experts gave their explanations based on the form of a dynamic ice load observed from tests. Engelbrektson (1977, 1989, 1997) conducted field measurements on the Norströmsgrund lighthouse and found different ice force modes with different ice speeds. Kärnä (1990) proposed that there are 4 kinds of ice force patterns, and they induce different types of structural responses.

Comprehensive full-scale tests were conducted on a monopod structure in Bohai Bay (Yue et al., 2004). Ice forces, ice velocity and structural displacement were recorded concurrently. The

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