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Experimental study of dynamic conical ice force

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ABSTRACT

Dynamic ice force is one of the key factors in the design and operation of narrow offshore structures in ice-covered areas. In the paper, a series of physical model tests were carried out to simulate field ice conditions on the oil jacket structures with an ice breaking cone in the Bohai Sea. The model tests involved two geometric scale factors (3 and 6), 3 structural models, and 3 ice sheets. In the total 17 groups of tests, the controlled parameters of ice velocity, ice friction coefficient, and the shape of the ice-resistant structure at the waterline were different. The time history of ice forces, accelerations of the model, and the ice–cone interaction process were recorded synchronously. Ice failure modes and global ice loads obtained from the model tests were compared with the data measured on the JZ20-2MUQ oil jacket platform. Similar to the results in the field measurements, two ice failure modes were observed on the cones in the lab test. The plate failure mode was observed on the inverted cone. For the upright cone, when the cone diameter was increased, the ice failure mode was transformed from the wedge failure mode into the plate failure mode and the ice load on unit area was decreased.

1. Introduction

Since the first oil platform was constructed in Mexico Bay in the 1960s, more and more offshore structures had been erected in the ice-covered area. Ice load is the dominant environmental stress for offshore structures in ice-covered areas. Some optimization designs were introduced to reduce or withstand ice load. For example, adding ice-breaking cones on conventional vertical legs could convert the ice crushing failure mode into the flexural failure mode because the compressive strength of ice is significantly higher than the flexural strength. The role of adding an ice-breaking cone in decreasing ice force was proved by theoretical research and laboratory tests (Izumiyama et al., 1991; Wessels and Kato, 1988). Conical and sloping structures were also widely adopted for bridge and offshore structures (Frederking et al., 1991; Määttänen, 1994; Mayne and Brown, 2000; Montgomery and Lipsett, 1980; Timco and Johnston, 2004; Wright, 2001; Yue and Bi, 1998).

However, various ice load calculation equations show distinct differences. During the design of specific structures in a certain sea area, conservative ice force calculation methods (Croasdale, 1978, 1984; ISO19906, 2010; Ralston, 1980) or the recommended ice force values obtained through the laboratory tests were adopted (Christensen et al., 1995; Croasdale et al., 1994; Huang, 2010; Timco et al., 1995). Due to the complex conditions of natural sea ice and the difference of structure styles, only the full-scale measurement system can provide the most credible ice force data. One of the most comprehensive full-scale measurement systems was conducted on conical jacket structures of the JZ20-2 MUQ Platform in the Bohai Sea. A lot of measured field data were obtained (Yue and Bi, 2000) and the dynamic ice force models were established (Qu et al., 2006; Yue and Bi, 1998; Yue et al., 2007) and applied in the design and analysis of ice-resistant offshore structures in the same sea area (Ji et al., 2011).

Because the limited field data measured in different sea areas show the significant difference (Brown, 2001; Määttänen, 1994; Yue and Bi, 1998), the data need a theoretical framework for conclusions. The factors of sea ice properties mainly include ice velocity, thickness, salinity, and snow on the ice. The laboratory test, in which parameters of ice and structure are easily controlled, can be used to validate the rules and mechanics of ice load. According to the testing purposes, previous tests can be divided into research tests and design tests. There are mainly two kinds of ice force tests for various purposes. First, the research tests were mainly used to analyze the influences of some parameters onr ice load or to establish the application models of ice load. Second, the design tests were mainly used to analyze the ice loads on specific structures in structure design, risk analysis, safety evaluation, and other applications (Christensen et al., 1995; Timco et al., 1992, 1995, 1997).

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In this paper, laboratory tests on cones were performed at two scale factors of 6 and 3 in the ice tank of the Hamburg Ship Model Basin (HSVA). In the laboratory tests, ice forces were examined under ice conditions with three cones, which represented conical jacket structures in the Bohai Sea. The model tests were performed and then analyzed with the data obtained through field measurements.

Firstly, this paper introduces the field measurement system and provides the data on measured ice loads on the JZ20-2MUQ Platform in the Bohai Sea. Secondly, the design and procedure of the tests are described in several aspects: the selection of scale factors, the determination of ice load model structure, and the components of the measurement system. The ice failure process and global ice load obtained in the model study are compared with the available data on the full-scale ice loads on the jacket platform. The results indicate that the ratio of the structure size at the waterline to ice thickness is the control factor of the ice sheet flexural failure mode. The ratio determined the effective pressure applied on the cones. These testing results can provide useful information for the prediction of the loads on a full-scale conical structure.

2. Full-scale measured ice force on the JZ20-2MUQ Platform

The Bohai Sea is the ice-covered sea area located at the lowest latitude in the Northern Hemisphere. The Bohai Sea has a three-month ice season every year mainly due to the cold air from the Eurasian Continent. The maximum single level ice thickness is about 0.3 m in winter, while ice ridge is seldom observed. The maximum ice velocity may exceed 1.2 m s^{-1}.

The jacket structures were widely applied in the oil recovery sea and experienced strong ice-induced vibrations in winter. The JZ20-2MUQ Platform, shown in Fig. 1, is a typical 4-leg steel jacket with ice-breaking cones, 3 levels of decks, and operating in a water depth of 15.6 m. The cylinder leg diameter is 1.76 m wide and the cone diameter is 4 m.

As shown in Fig. 1, the JZ20-2MUQ Platform was equipped with a comprehensive monitoring system, which was composed of load panels for direct measurement of ice load, accelerometers on deck for structural vibration measurement, and video cameras for recording of ice conditions and the ice–cone interaction process.

Fig. 2 shows the schematic sketch of load panels. The cone surface is connected with the rigid cover through elastic components, and the external load is transmitted to the cone surface through the elastic components of the load panel.

Load panels composed of six pressure strain gauges were installed on the north of the ice breaking cone of the JZ20-2 MUQ Platform, and these covered an angle view of 48° (Fig. 3). Arc lengths of the upper and lower edges of the load panels are, respectively, 1.73 m and 1.67 m. The effective ice-facing width is 0.9 m. Ice force measurement width is 0.8 m. The overall mass of the panel is about 900 kg.

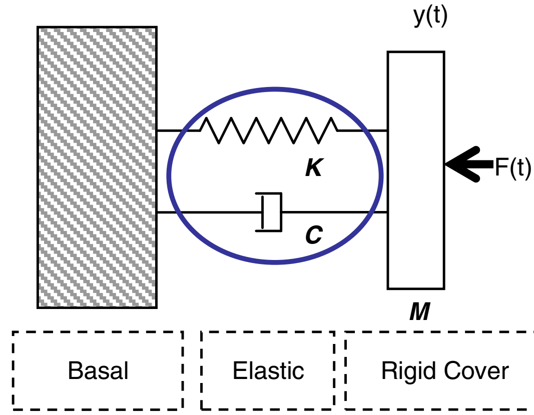


Fig. 2. Physical model of the ice load panel.

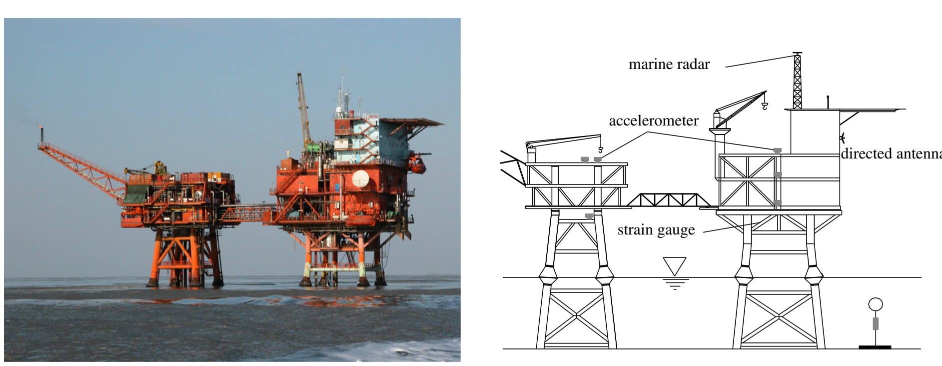
The measured field data indicate that the maximum ice-induced vibration of JZ20-2MUQ may exceed 0.6 m s^{-2} and that the dominant failure mode is the flexural failure. The time history of ice load is the periodical type with triangle pulse, as shown in Fig. 4.

The ice load panel worked well in winter from 2000 to 2004 and a large amount of ice load data were obtained (Qu et al., 2006). The maximum ice load exceeds 50 kN. Ice load events in two winters are listed in Table 1.

3. Model test program

3.1. Testing facility

The model test was carried out in the ice tank of the Hamburg Ship Model Basin (HSVA). The ice tank is 78 m long, 10 m wide, and 2.5 m deep (the tank dimension in its deep end is 12 m $*$ 10 m $*$ 5 m). The tank is located in a large cold room, in which the lowest temperature can reach −28 °C. The model was mounted in a large towing carriage which could travel along the whole length of the tank. Tests were conducted by moving the model through a stationary ice sheet at a determined rate to simulate the interaction process. The carriage could be driven under the load up to 50 kN and the driving speed ranged from 1 to 3000 mm/s.



(a) The JZ20-2 MUQ platform in situ (b) Schematic diagram of the measurement system on JZ20-2 MUQ

Fig. 1. The JZ20-2 MUQ Platform and schematic diagram of the measurement system. (a) The JZ20-2 MUQ Platform in situ. (b) Schematic diagram of the measurement system on JZ20-2 MUQ.