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Model tests of four-legged jacket platforms in ice: Part 1. Model tests and results

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A B S T R A C T

Two series of model tests were performed to investigate the dynamic ice loads on two types of four-legged jacket platforms and the consequently structural responses. The first test series was carried out with cylindrical models and the second test series with conical models at the water level. To simulate the ice induce vibrations on multi-legged structures, a new series of test equipments was designed. The ice load on each model leg, structural displacements in three directions, and foundation reactions in two directions were measured during the tests. Different ice failure modes and structural responses were observed for different ice conditions and structural stiffness values. This paper provides a description of the test techniques and the experimental results. The important test phenomena are also discussed in this paper.

1. Introduction

Multi-legged jacket platforms have been widely used in ocean oil explorations. This type of platform is always strongly supported but with high compliance due to its heavy supports on decks. Ice moving against such structures can induce severe vibrations. With the development of oil explorations in cold region seas, more and more remarkable ice induced vibrations on these structures occurred. Some violent ice induced vibration events even threaten the securities or normal production exercises of the structures. For example, platforms in Bohai bay have experienced several violent ice induced vibrations (Wang, 1983; Wessels and Jochmann, 1990; Yue et al., 2001).

For vertical structures, the control mechanism of ice induced vibrations still remains controversial in ice mechanics community. Some scholars state that the ice induced vibration on vertical structure is a kind of forced vibration. Peyton (1968) and Neil (1976) considered the steady-state vibration caused by ice to be a resonant vibration relevant to the failure length of ice. Similar conclusions were obtained in field and lab tests by Michel (1978), Sodhi (2001), Sodhi and Morri (1986). They reported that the failure frequency of ice is directly proportional to ice velocity and inversely proportional to ice thickness. And the resonant vibration may occur when the ice failure frequency meets with the natural frequency of the structure. Another group of researchers hold the viewpoint that the control mechanism of ice induced vibrations on vertical structures should be attributed to the interactions between ice and structures. Based on field observations in Kulk gulf, Matlock et al. (1969) established a numerical model on the consideration of the displacements and elastic deformations of ice sheet and structure. Määttänen (1977) considered the breaking length of ice being controlled by structure, and took the cause of ice induced vibration for the negative damping factor in ice–structure interaction. Later on, this consideration was developed into the self-excited vibration theory. Karna and Turunen (1989, 1990) analyzed the control mechanism from the aspect of energy transformation. Recently, the idea of analyzing ice induced vibrations on vertical structures by using the "interaction coefficient I" was put forward (Huang et al., 2007a). Palmer et al. (2010) presented a dimensional analysis of the problem, and showed that there is a correlation between the different kinds of cyclic movements that occur and a dimensionless parameter akin to reduced velocity in vortex-induced vibration. Presently, this problem is still being widely discussed.

It has been proved by many scholars that the ice force on a conical structure is lower than that on a smaller-sized cylindrical structure (Barker et al., 2005; Hirayama and Obara, 1986; Ralston, 1977; Sodhi et al., 1987; Wessels and Kato, 1988). The ice force reduction is mainly because that the well-designed conical structure may change the ice failure mode from crushing to bending. Thus, many offshore structures in cold regions are designed into conical shape as the offshore wind turbine foundations in Denmark; or installed ice-breaking cones on cylindrical piles at the water level as oil platforms in the Bohai Bay (Fig. 1).

Installing ice-breaking cones may also generate problems. Yue and Bi (1998, 2000) reported that vibrations still occurred on oil platforms in the Bohai Sea after ice-breaking cones had been installed. However, Karna et al. (2007), basing on field observations on the Kemi-I lighthouse in the Baltic Sea while the cone was present, stated that installing ice-breaking cones on vertical structures can also improve the ice induced vibration condition. Such problems raised the attentions of researchers. Karna et al. (2003) studied detailed issues on the conical

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Fig. 1. Platform JZ20-2 MUQ & MNW.

model vibration through lab tests. Barker et al. (2005), basing on model tests, found that the ice force on conical structures appears as stable period characteristic, caused by the bending failure of ice sheet. Multi-time failures of ice sheet were experimentally observed during the interactions between ice and conical structures by Huang et al. (2005). According to this ice failure mode, dynamic ice force function model on conical structures was established by Huang et al. (2007b).

Timco (1987) performed a state-of-the-art review of ice forces on multi-legged structures. This review clearly showed the paucity of information on ice loads on multi-legged structures, in terms of field studies, model studies and analytical models. Although some research works were successively performed by Christensen et al. (1995), Kato (1990), Shi et al. (2002), and Timco et al. (1992, 1995), more works are still needed to understand the interacting processes between ice and multi-legged structures. This paper aims to investigate the dynamic ice loads on four-legged jacket platforms with or without cones at water level and the consequently structural responses.

2. Experimental procedures

2.1. Test facilities

The tests were performed in the ice tank at the Ice Engineering Laboratory of Tianjin University. The tank, which is 20 m long by 5 m wide and 1.5 m deep, is housed in a insulated room that can be cooled down to an air temperature of −22 °C. By varying the room's air temperature, ice sheets can be grown, tempered or melted. Two carriages that can travel the length of the tank span the tank. The big one is the main carriage which is designed for loads up to 5 ton with a speed range from 1 to 500 mm/s. The small one is the service carriage which is used to install the models on the main carriage or push the ice through the models in some tests.

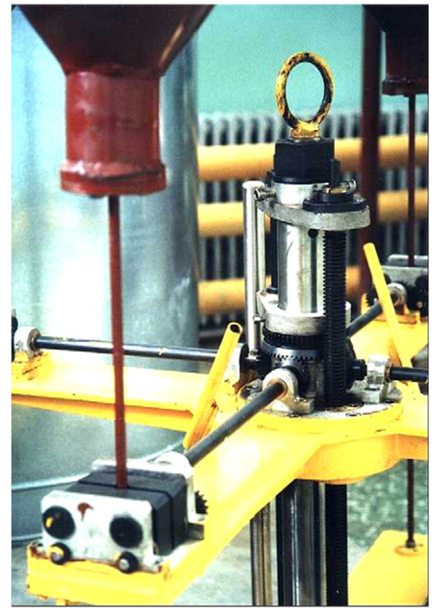

Fig. 3. Picture of the lifting frame details.

2.2. Compliant multi-legged models

In the past decades, the vibrations of single-degree of freedom (SDOF) structures in ice have been generally studied in laboratories (e.g. Barker et al., 2005; Huang et al., 2007b; Izumiyama and Uto, 1997; Izumiyama et al., 1994; Toyama et al., 1983). These tests all used a rigid structure and simulated the compliance of the foundation. Such equipments were also used to investigate the ice induced vibrations of multi-degree of freedom (MDOF) structures by Timco et al. (1992, 1995). Another type of test that models the full elasticity of the structure itself was used to simulate the offshore structure Molikpaq (Cornett and Timco, 1997; Timco et al., 1997). For multi-legged structures, interference effects that will influence the behaviors of ice loads

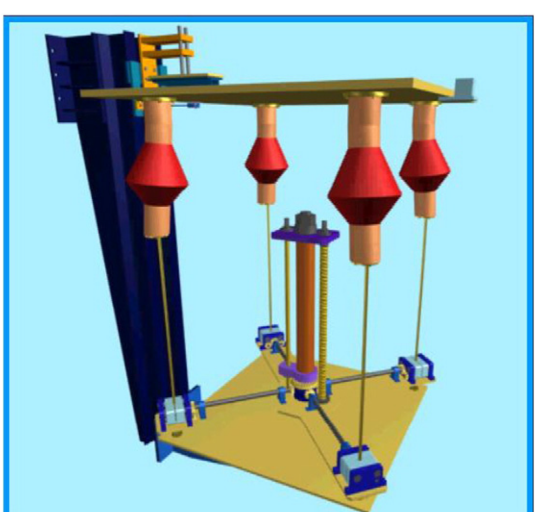

Fig. 2. 3D-plot of the compliant multi-legged model.

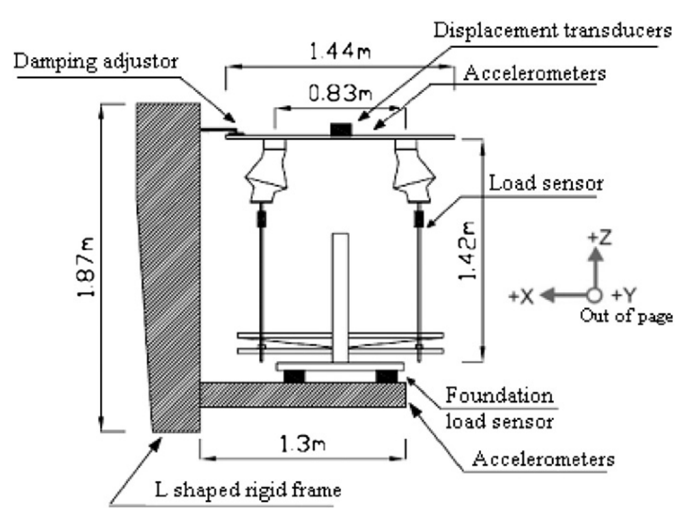

Fig. 4. Arrangements of the compliant model system.