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Cold Regions Science and Technology 49 (2007) 151–160
cold regions science and technology
www.elsevier.com/locate/coldregions

Model test study of the interaction between ice and a compliant vertical narrow structure

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Received 26 December 2005; accepted 1 January 2007

Abstract

From 2004 to 2005, a series of model tests were performed to explore the mechanism that controls the procedure of ice induced vibration of vertical narrow pile. The interaction of ice and structure was found to be the control mechanism in the model test study, and the intermittent ductile–brittle crushing was also found to be the most important characteristic in the process of interaction. Based on this important phenomenon, a new concept – interaction coefficient – was set up in this paper. This parameter directly reflects the interaction level of ice and structure.

Keywords: Ice induced vibration; Compliant vertical pile; Model test; Interaction coefficient

1. Introduction

Ice induced vibration is the peculiar phenomenon of compliant structures while the dynamic ice force is acting on it. Most of the ocean engineering structures used in oil explorations have high compliance, such as the jacket platforms being widely used in Bohai Sea. With the development of oil explorations in cold region seas, more and more remarkable ice induced vibrations occurred. Some violent ice induced vibration events even threaten the securities or normal production exercises of the structures. For example, the offshore structure Molikpaq experienced severe vibration due to ice loading while drilling for hydrocarbons in the Canadian Beaufort Sea in 1986 (Jefferies and Wright, 1988); in the winter of 1999, platform JZ20-2 also experienced violent ice induced vibration which induced breakage of the platform pipes (Yue, 2004).

While the failure of ice sheet before conical structure is a typical bending failure, which leads the ice force to have stable periodic characteristic, the viewpoint that the problem of ice induced vibrations on compliant conical structures can be attributed to compulsive vibration theory has been widely accepted in ice mechanics community. However, researchers diverge on the problem of the mechanism that controls the procedure of ice induced vibrations on vertical structures.

Some experts such as Peyton (1968) and Neil (1976) have the opinion that steady state vibration caused by ice is a resonant vibration that relates to a concept known as the failure length of ice. Similar conclusions were obtained in field and lab tests by Michel (1978), Sodhi (2001), Sodhi and Morris (1986). They reported that that the failure frequency of ice is directly proportional to ice velocity and inversely proportional to ice thickness.

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0165-232X/$ - see front matter © 2007 Elsevier B.V. All rights reserved.
doi:10.1016/j.coldregions.2007.01.004

Resonant vibration may arise when the failure frequency is close to the natural frequency of the structure.

Other experts took the interaction between ice and a flexible structure as the control mechanism of the procedure of ice induced steady vibration. Basing on the field observation 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. Some scholars hold the viewpoint that the break size of ice is controlled by structure, and the cause of ice induced vibration is the negative damping factor engendered in course of ice–structure interaction (Määttänen, 1977). Subsequently, this consideration was developed into the self-excited vibration theory, which is supported by quite a few scholars. On the basis of self-excited vibration theory, Yue (2004) analyzed the problem from a new aspect that considered the material characteristics of ice and the feedback effect of the structure response. Some scholars also analyzed the problem from the aspect of energy transition (Karna and Turunen, 1989, 1990).

Presently, these two theories are still being widely discussed in the ice mechanics community. In fact, the key point that judges the control mechanism should be fixed on distinguishing the dynamic characteristics of ice force. If the ice force that excites steady vibration on structure has a stable periodic characteristic, the structure response could be attributed to compulsive vibration. Contrarily, if the ice force that excites steady vibration on structure has no stable periodic characteristic, the structure response should be attributed to ice–structure interaction.

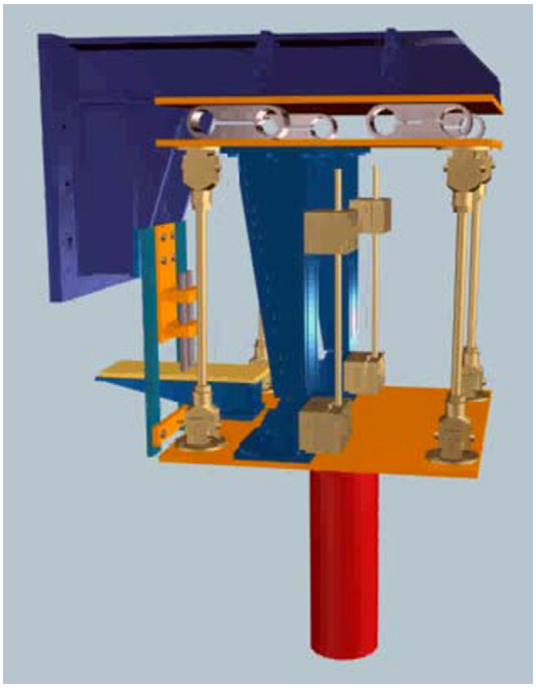

Fig. 1. Test equipments.

Table 1
Test conditions

f_N, Hz	K, kN/m	h, mm	σ, kPa	V, mm/s
4.29	23.81	26–48	55–210	5–450
6.25	27.44	26–48	55–210	5–450
6.64	35.78	26–48	55–210	5–450
12.5	254.8	26–48	55–210	5–450

Financially supported by the National High Technology Research and Development Program of China (863 Program), a series of dynamic ice force tests were performed in the Ice Engineering Laboratory of Tianjin University from 2004 to 2006. The tests refer to several types of model structures, including single cone, single vertical pile, multi-cone and multi-pile. All the model structures were equipped with enough compliance to vibrate in the acting of the advancing ice sheet. Some progresses achieved in the single pile tests will be given in this paper.

2. Model tests

On the basis of the “compliance simulator” designed by Timco et al. (1995a,b), similar equipments were used in the compliant vertical model tests, as shown in Fig. 1. The test model mainly consisted of two parts, rigid upper frame and lower “floating table”. To provide complete freedom in the horizontal plane and high rigidity in the vertical direction, the floating table was mounted to the rigid frame at the four corners through four bars, which had universal joints at each end. Two large vertical steel plates were separately fixed on the upper frame and lower table. These plates firmly supported two steel rods, with each end being separately clamped on the upper and lower plates. By changing the bar length and diameter, the model stiffness could be adjusted to the correct value. By adjusting the mass of the table, the correct natural frequency for the structure could be achieved. The lower table was drilled a circle hole in the center to mount the vertical model. Relative to the carriage moving direction, a damping adjustor was installed on the back of the lower table.

The test system included four foundation dynamometers, one load senor and one displacement transducer. The foundation dynamometers were installed between the upper frame and carriage to measure the foundation loads. The vertical model was mounted to the lower table