Reinvestigation of Ice-Induced Vibrations of Conical Jacket Structures Using Dimensionless Parameters

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INTRODUCTION

Ice action is the dominant environmental action on offshore structures in ice-infested cold regions (Sanderson, 1988). When an ice sheet moves against narrow structures, such as a jacket offshore platform or an offshore wind turbine, dynamic ice action may arise due to cyclic failure of the ice sheet (Sodhi, 1988, 2001; Yue et al., 2006; Wang et al., 2014). According to lab tests and in-field observations in the Cook Inlet, Baltic Sea, and Bohai Sea, cyclic crushing failure of the ice sheet on vertical jacket structures (Fig. 1a) may induce severe structural vibrations (Yue et al., 2001, 2002; Bjerkås et al., 2013). A special dynamic ice–structure interaction phenomenon known as frequency lock-in has been reported on vertical jacket structures when the ice velocity is in a certain range, which can cause severe harmful vibrations (Yue, Guo, and Kärnä, 2009; Palmer et al., 2010; Bjerkås et al., 2013). It is well known that flexural strength of ice is much lower than its compressive strength, and bending failure is the major failure mode of ice on conical or slope structures. In view of such characteristics, ice-breaking cones have been installed on vertical jacket structures at the waterline in order to reduce the ice action and to eliminate the frequency lock-in observed in cases of interaction between the ice sheet and the compliant vertical structure. However, in-field observations have shown that ice-induced vibrations (IIV) still exist on conical jacket structures but that the cause is the cyclic bending failure of the ice sheet (Yue et al., 2006; Yue, Qu, et al., 2007) (Fig. 1b).

Ice-induced vibrations can cause several problems, such as fatigue failure of tubular joints, crew discomfort, and gas leakage due to flange loosing (Yue, Liu, et al., 2007). Based on in-field observations in the Bohai Sea, Yue et al. (2008) summarized that the failure modes of ice-resistant jacket structures could be categorized into two types: the structural failure and the nonstructural failure. The structural failure includes extreme deformation and stress under extreme static ice action and the fatigue failure of the tubular joint under dynamic ice action, while the nonstructural failure related to the magnitude of ice-induced deck acceleration includes damage of the equipment on the platform and crew discomfort. Thus, ice-induced acceleration is treated as a key issue for ice-resistant jacket structure.

From the structural analysis point of view, if the time-varying ice action is known, the ice-induced acceleration can be obtained easily. However, obtaining the accurate time-varying ice actions on conical structures is nontrivial because of the significant velocity effects of the conical structure ice-breaking action (Matskevitch, 2002) and the possible ventilation effects for downward cones in the ice block rotation phase (Lu et al., 2012).

Fig. 1 Failure of the ice sheet: (a) crushing failure of the ice sheet against vertical jacket structures; (b) flexural failure of the ice sheet against conical jacket structures