Bounds on Iceberg Motions During Contact With Subsea Equipment and the Seabed

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ABSTRACT

The design of subsea systems in ice prone environments must consider the potential for interaction with ice features. Many methods designed to protect subsea equipment from ice contact have been previously investigated and utilized; the most common of which is open glory holes.

Many models have been developed to simulate ice interaction events. This paper begins with a review of related literature to date. The review summarizes kinematic and numerical models that have been developed to study ice feature behavior and ice interaction with the seabed and subsea infrastructure.

Additionally, an analytical tool was developed using MATLAB in order to model ice kinematics for ice features contacting structure and the seabed. The model examines heave and pitch of the ice feature during interaction, as well as physical limits of the ice feature. Results and future considerations are presented.

KEY WORDS: Iceberg contact; iceberg gouging; iceberg motions; heave; pitch.

INTRODUCTION

As the worlds supply of conventional oil and gas decreases and demand steadily increases, utilizing reserves that, at one time would have been considered uneconomical, is now becoming a reality. It has been estimated that Arctic and harsh environment regions contain 15% to 25% of the world’s petroleum reserves (Kenny et al., 2007a; Pike et al., 2011a). However, operating in Arctic and harsh environments poses many challenges, including remote locations, harsh weather and extreme temperatures, as well as many complications due to the presence of ice.

Free-floating and gouging ice features pose a threat to the mechanical integrity of subsea equipment (e.g. wellheads, manifolds) and pipelines that protrude above the mudline. These ice features may contact, and damage or destroy the subsea equipment. On the Grand Banks, offshore Newfoundland, Canada, the annual contact probability for a 25 m diameter structure ranges from $10^{-4}$ to $10^{-3}$ for heights of 1 m to 10 m above the mudline (Croasdale et al., 2001). Various protection schemes for structures protruding above the mudline have been proposed that include protective external structures, berms and sacrificial elements (Doha, 2007, Fowlow, 2007; Pike, 2008). For other ice environments, such as the Beaufort Sea, Caspian Sea and offshore Sakhalin Island, the ice features may have weaker, unconsolidated ice keels (e.g. first year pressure ridge) with significantly greater incursion rates and contact frequencies (Caines, 2009).

In contrast, the annual contact probability for subsea structures located below the mudline is $10^{-5}$ for the Grand Banks environment. Thus, from a risk perspective there are significant advantages for employing burial protection strategies. Ice gouging features, however, may undermine protection structures and damage buried subsea infrastructure through direct contact or imposed geotechnical loads and subgouge soil deformations (Kenny et al., 2007b; Pike, 2008). Gouge features can be kilometers long, meters deep, and tens of meters wide (Barrette, 2011). The conventional practice for protecting subsea equipment, such as wellheads, xmas trees and manifolds, is through placement of the subsea infrastructure within excavated seabed depressions. This concept was originally advanced for application in the Canadian Beaufort Sea (Stewart & Goldby, 1984), and has since been utilized on the Grand Banks for the Terra Nova and White Rose field developments on greater scale through subsea excavated drilling centres (EDCs). For the open excavation protection schemes, the risk of damage due to debris pushed into the excavation, or direct contact from ice features due to hydrostatic instability (i.e. roll, pitch) or dynamic action (i.e. heave due to changing water levels associated with wave troughs) must also be considered. Other design concepts for subsea protection through burial include perimeter reinforcement structures within the excavation (Fowlow, 2007; Pike, 2008; Ralph et al., 2011). Although the cost associated with subsea excavations is high, the cost can be justified where there exists sufficient multiple subsea assets, such as templates (Fowlow, 2007; Pike, 2008). However, for protecting a single peripheral wellhead, this cost would be much too great to justify; therefore, alternative protection methods are required in such scenarios.

The interaction of an ice feature with subsea structures and the seabed is a complex, nonlinear event associated with large deformations, plastic material behaviour, and contact mechanics (Kenny et al, 2007b;