ABSTRACT

Punch tests were carried out on manufactured freshwater ice rubble keels during the Pipeline Ice Risk and Mitigation (PIRAM) and Development of Ice Ridge Keel Strength (DIRKS) projects. The majority of the tests were carried out while the keel was still in contact with the soil tray, as would be the condition for a grounded sea ice ridge or stamukha. Results showed that peak ice pressures on the platen ranged from 61 kPa to 427 kPa, with an average value of 192 kPa and a standard deviation of 131 kPa. A conservative value for the bearing capacity of grounded freshwater ice rubble can be approximated to be 550 kPa (calculated by taking the mean plus three standard deviations).

KEY WORDS: Ice Ridge Keels; Punch Tests; Grounded; Pipelines; Local Ice Pressures

INTRODUCTION

The continuously increasing demand for energy has pushed hydrocarbon exploration into arctic and northern environments. While industry is evolving in this relatively new area of expertise, knowledge gaps remain in the engineering of both pipelines and structures to withstand ice loading. Subsea pipelines are often at risk of being damaged by gouging ice features, such as icebergs or sea-ice ridges. This occurs when an ice feature drifts into shallow waters and contacts the seabed, producing long narrow gouges or scours that can be meters deep, tens of meters wide and hundreds of meters long.

Ice gouging mechanisms are very different, depending on the ice type. Icebergs are solid bodies that do not experience significant failure while gouging the seabed. Ice ridges consist of an assembly of ice pieces (ice rubble) that are typically bonded together to form a competent matrix and, as such, can deform though shear, tension and compression. To date much of the research on ice gouging has focused on icebergs. This is not only because icebergs produce the deepest gouges but also due to the complexities involved with modelling both the ice rubble and soil deformation, and the interaction between both materials. Understanding these processes is, however, vital for development of subsea infrastructure in regions where sea ice ridges are the dominant ice hazard (e.g. Beaufort Sea, North Caspian Sea and Offshore Sakhalin).

A number of tests have been conducted over the years to investigate the mechanical properties of ice rubble. Earlier tests were conducted in the laboratory and eventually shifted towards in situ tests on actual ice rubble/ridges. Reviews of these works can be found in (Bailey et al., 2015; Ettema and Urroz, 1991, 1989; Liferov and Bonnemaire, 2005; Timco et al., 2000; Timco and Cornett, 1999). In situ tests have been aimed mostly at loads on structures due to floating ice ridges. The question is how to apply data from floating ice ridges to the problem of a gouging ice keel.

To investigate the ice rubble-gouging process, a series of large-scale tests were conducted in the NRC ice tank facility in St. John’s, Newfoundland, as part of the Pipeline Ice Risk and Mitigation – PIRAM (Bruce et al., 2012; Phillips et al., 2012) and Development of Ice Ridge Keel Strength – DIRKS (Bailey et al., 2014a, 2014b) Projects. Tests consisted of deforming a manufactured freshwater ice rubble keel using a custom-built frame that applied a surcharge pressure to the top of the keel whilst a soil tray was pushed horizontally into the base of the keel. If an intact keel remained at the end of the test, a punch test was carried out. The majority of the tests were carried out while the keel was still in contact with the soil tray, as would be the condition for a grounded sea ice ridge or stamukha. These punch tests are the subject of this paper and are considered important when considering the design of structural elements for local pressures. The result from one full-scale grounded punch test conducted in the 1998 Canadian ridge testing trials (Croasdale and Associates, 1998) will also be presented and compared with these results.

ICE KEEL PRODUCTION

The ice keels in the PIRAM and DIRKS test program were produced from freshwater ice rubble, which was produced in a...