Advanced Continuum Modeling to Determine Pipeline Strain Demand Due to Ice-Gouging

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A critical factor for economical design of offshore Arctic pipelines is the burial depth requirement to protect the pipeline from ice-gouge hazards. The current methodology to determine pipeline strain demand due to ice-gouge hazards is based on Winkler-type soil-spring structural models. Due to necessary simplifications and lack of full-scale verification data, this empirical method can be overly conservative and may lead to unrealistic burial depth requirements.

This paper presents an advanced 3D continuum modeling approach as an alternative to the current empirical methodology. These advanced models provide more realistic simulation capability for modeling the ice-gouging process, can provide more accurate estimates for pipeline strain demand, and can potentially reduce the required burial depths and costs. Continuum models, once validated using large-scale field tests, can be used to advance the reliability and cost effectiveness of design for offshore pipelines subjected to ice-gouging.

INTRODUCTION

As the industry pushes into frontier Arctic environments, offshore pipelines must be designed to withstand unique loading conditions of seafloor gouging by drifting sea ice ridges and icebergs. Offshore Arctic regions may contain several types of ice features that are capable of scouring the seafloor, including icebergs, first-year ice ridge keels and multiyear ridge keels. The ice features are continuously moving under the action of environmental forces (e.g. wind and ocean currents) and, whenever their draft is larger than the local water depth, they scour the seabed producing the characteristic process of ice-gouging. Fig. 1 shows a schematic illustration of the ice-gouging process.

Pipelines are assumed incapable of safely withstanding the contact with gouging features and therefore must be buried deep enough for contact to be avoided. In addition, ice-gouging creates a significant displacement field in the soil region directly beneath the gouging surface. Woodworth-Lynas and Guigne (1990) documented field observations of relic gouges showing that shear planes and large soil deformations may occur to a significant depth (up to a few meters) below an ice-gouge. These displacements are referred to as subgouge displacements and are transferred to the buried pipeline through mechanical interaction with the surrounding soil. If the pipeline burial depth has not been properly selected, the resulting pipeline displacements may produce large strains and ultimately failure.

Numerical modeling of the ice-gouging process is challenging due to the complex interaction between ice, soil and pipe and the complex material behavior of soils. Two very different modeling approaches are currently available in the industry for calculating pipeline strain demand due to ice-gouging: Winkler soil-spring-based structural models and continuum models. Due to limitations of early Finite Element (FE) Analysis techniques in the 1990s as described by Abdalla et al. (2009), such as inability to handle extreme soil deformations and very high computational cost, the simpler soil-spring-based approach has traditionally been used for design of pipelines subjected to ice-gouging hazards. Advancements in FE techniques and significant improvements in computational capabilities over the last few years have overcome these limitations and made analysis of the ice-gouging process using advanced continuum models more tractable. This paper considers the continuum-based approach as an alternative to the soil-spring-based methodology.

WINKLER SOIL-SPRING-BASED MODELING APPROACH

The current methodology to determine pipeline strain demand due to ice-gouge hazards is based on Winkler soil-spring structural models, where the pipe is discretized with beam (or elbow) elements that are connected at each node to nonlinear springs acting in all 3 directions and representing the interaction with the surrounding soil. A schematic representation of this idealization is provided in Fig. 2.