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Use of Bayesian Network for Risk-Based Fatigue Integrity Assessment: Application for Topside Piping in an Arctic Environment

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In the North Sea, hydrocarbon release (HCR) from offshore topside piping that is inherently degrading because of vibration-induced fatigue (VIF) has been a significant challenge. This challenge is further exacerbated when the operating assets are located in Arctic environments, especially because of higher temperature gradients and other operational challenges. The result is a significant increase of VIF failure of topside piping, which causes a higher risk of potential HCR in Arctic environments. The "zero oil spill" requirement in the Arctic region requires operators to follow stringent guidelines to mitigate the risk of VIF failure of topside piping. In this regard, this paper demonstrates the application of the Bayesian network (BN) for risk-based fatigue integrity assessment of the topside piping. The value of the calculated risk depends upon the values of likelihood of failure (LoF) and consequence of failure (CoF). The value of LoF in turn depends upon the measured vibrational velocity (coupled with the vibration assessment criteria of the Energy Institute guidelines) and probabilistically estimated remnant fatigue life (RFL) of topside piping. Likewise, the CoF has been assessed from safety, environmental, and business perspectives. The BNs have been modelled using GeNIe and have been utilized to estimate the risk. The outcome of the fatigue integrity assessment using the proposed approach is the categorization of piping into various risk groupings. Piping in the high-risk category is thereby prioritized for inspection, thus preventing HCR in the fragile Arctic region. An illustrative case study, demonstrating the usability of the proposed approach, is presented.

INTRODUCTION

The rapid growth in demand for hydrocarbons and the decline of production in existing fields have induced the petroleum industry to extend their exploration and production activities to the Arctic regions (Basel et al., 2008; Hasle et al., 2009). The U.S. Geological Survey finds that the Arctic region holds approximately 22% of the world's undiscovered conventional oil and natural gas resource base, approximately 30% of the world's undiscovered natural gas resources, approximately 13% of the world's undiscovered oil resources, and approximately 20% of the world's natural gas liquid (NGL) resources (Gautier et al., 2009). However, Artic petroleum operations have undergone quite stringent regulatory requirements, due to higher environmental sensitivity (Regjeringen, 2014). Hence, the exploitation of the Arctic reserves depends on the level of technology, as well as assessment and control readiness levels at the design, construction, and operational (i.e., inspection, maintenance, and modification) phases. For instance, compared to non-Artic regions, these regions have higher temperature gradients and increased susceptibility to brittle fracture of metals, human factors, etc. (Basel et al., 2008; Ratnayake, 2017). Hence, it is vital to develop effective methodologies to assess the risk of potential failures.

The lowest possible ambient temperature on the Norwegian continental shelf (NCS) is considered to be approximately −20°C. For instance, the design temperature for the Snøhvit project has been selected as −23°C (Thaulow et al., 2006). However, in the Arctic regions, temperatures can be as low as −40°C. Hence, the design temperatures should be as low as −60°C (Thaulow et al., 2006). The extreme low-temperature operations impose the toughest requirements in the assessment and control of structural integrity and functionality. In this context, to meet the requirements for safe exploration and operation, the development of the most reliable and robust technology is needed, as "zero-leakage" and "maintenance-free" solutions must be sought and qualified (Thaulow et al., 2006). Hence, approaches to support assessment and control processes to introduce robust technological solutions need to be developed.

Optimized designs and use of super materials [high-strength steels, with yield strength between 50 ksi (approximately 345 MPa) and and 86 ksi (approximately 593 MPa)] in the construction of the latest Arctic production and process facilities (P&PFs) have caused the significant reduction of wall thickness of topside piping compared to conventional P&PFs. Furthermore, a small reduction in the wall thickness due to erosion and/or corrosion also has had a significant influence on piping vibration under the same/changing flow velocities. As a result, topside piping made of super materials tends to be more prone to vibration-induced fatigue (VIF) failure. Consequently, VIF failure of the aforementioned asset leads to hydrocarbon release (HCR), which must be prevented because of the "zero-oil spill" requirement in the Arctic region. Thus, in the authors' view, the risk-based fatigue integrity assessment of topside piping is mandatory, in order to prevent HCR from topside piping and to enhance process safety on offshore oil and gas (OOG) platforms in the Arctic

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