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Reliability assessment of marine floating structures using Bayesian network

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ABSTRACT

Marine floating structures are widely used in various fields of industry from oil and gas to renewable energy. The predominant dynamic responses of these structures are controlled by mooring lines. In recent years, a number of high-profile mooring failures have highlighted the high risk of this element in floating structures. A reliable design of mooring liness is necessary to improve the safety of offshore operations. This paper proposes a novel methodology to conduct reliability analysis of moored floating structures using Bayesian network (BN). The long-term distributions of extreme responses of the floating object are estimated using analytical frequency domain method, while mooring failure probability is estimated using limit state function in the proposed BN framework. Application of the methodology is demonstrated by estimating the failure probabilities of a floating cylinder with tensioned mooring system. The proposed study also explains how the hydrodynamic and reliability analysis could be integrated with BN to assess the overall safety of the offshore structures. The methodology presented can be employed to mitigate associated risk with marine structures brought about by stochastic hydrodynamic loads.

1. Introduction

Marine floating structures are widely used in the oil and gas industry, marine transportation and exploration areas, and renewable energy applications. Conceptual design scenarios for each of these structures are based on environmental loads such as wave, wind and currents. Due to the stochastic behaviour of the sea environment, different types of failures are expected to occur, however it is necessary to improve the safety of marine structures during their lifetime. In the past few years, there has been an increasing focus on analysis of the extreme loads on oil and gas platforms [1–3], and have growing investigations on human reliability assessment in marine harsh environment [41,42]. To explain the complexity of the problem and the various factors involved in the field of marine engineering, a review of marine reliability analysis adopted from previous research is schematically illustrated in Fig. 1.

Previously, in order to conduct mooring failure analysis, traditional reliability methods were applied, such as the first order reliability method (*FORM*) and second order reliability method (*SORM*) applied by Gao [4], and Frosing and Jansson [5], and Nazir et al. [40]. Siddiqui and Ahmad [6] suggest that failure probability of a mooring system may increase when one mooring system has to be replaced or repaired due to partial or complete damage. With emphasis on the importance of progressive failure, or the entire collapse of the floating system, they investigated reliability of the mooring system of a Tension Leg Platform (*TLP*). Li et al. [7] analysed the effect of downstroke on the reliability of tendon unlatching using FORM and SORM, rather than considering the loss of tendon tension.

Although there are a number of methods in the literature for reliability analysis of marine structures, Bayesian statistics is recommended by Sørensen [8]. An extensive review of BN and probabilistic tools including a wide range of BN applications are provided by Nielsen et al. [57]. Among the current probabilistic models for risk and reliability analysis, Bayesian approach is a promising tool that allows reflection of available knowledge on the process (Abaei et al. [9], Groth et al. [52], Khakzad et al. [54], Musharraf et al. [55], Montewka et al. [56], Trucco et al. [59]). Since Bayesian approaches are capable of considering continuous variables in a discrete format [9–11], it is possible to conduct the inference of more complicated stochastic relationships among random variables in the network, i.e. each variable may have more values than true or false (such as different level of storm conditions), and not all the dependencies have to be deterministic (such as utilities for decision making [33]). In comparison, other probabilistic models such as FORM and SORM are not well suited to conduct risk and reliability analysis efficiently [10]. Recent research has applied BN to engineering fields such as corrosion on steel structure and condition

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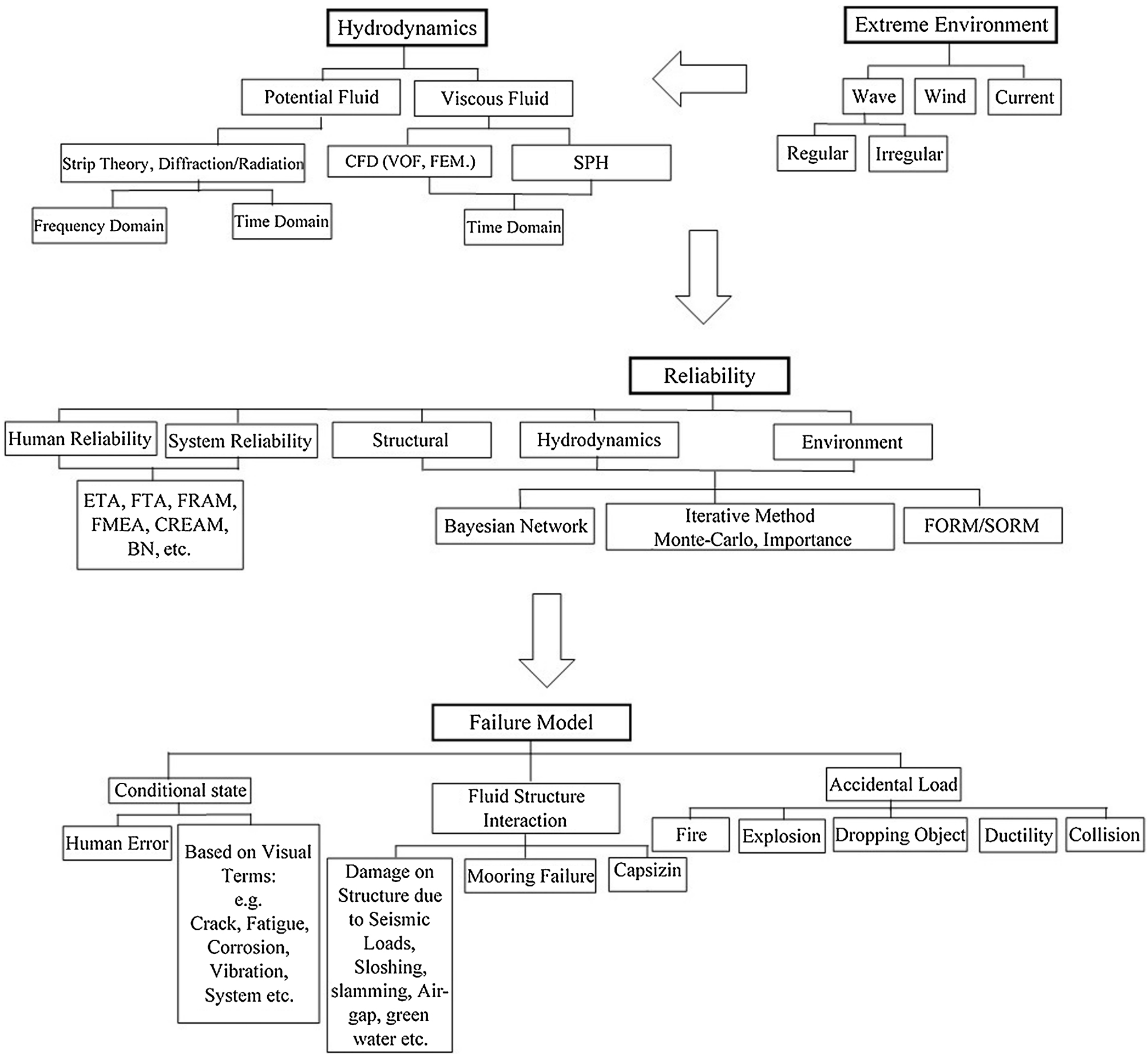

Fig. 1. Accident modeling framework applied to marine environment.

monitoring [11–13]. Wang et al. [14] used Object Oriented Bayesian Network (OOBN) to investigate the failure probability of different types of Australian bridges in terms of both structural reliability and conditional-based reliability. Morales-Napoles et al. [15] applied BN as a tool for assessing the failure risk of earth dams providing a conceptual framework for implementation of continuous stochastic variables in BN.

While the application of BN in reliability analysis of marine application is shown by previous researchers [[19],10,16–18,36,46], it is still necessary to integrate the probabilistic and hydrodynamic analysis of marine floating structures for risk assessment purpose. The risk assessment of systems or components such as moorings requires a probabilistic damage model or inspection and monitoring database. Referring to previous studies, BN is a promising and efficient approach in reliability analysis compared to the traditional methods developed by Vazquez-Hernandez et al. [19], Montes-Iturrizaga et al. [20] and Vázquez-Hernández et al. [21]. In this study, a new methodology for assessing the reliability of floating offshore structures using BN and frequency domain analysis is developed. The strength of the framework is its computational efficiency when performing Bayesian updating integrated with hydrodynamic response of the structure for estimating reliability of the operation and determining optimum design point of critical components such as mooring lines. To demonstrate the application of the developed methodology, a floating renewable energy substructure with tensioned mooring is considered as the case study. A limit state function for critical surge response is derived analytically based on the Potential theory and Hooks law. The response based stochastic variables induced by hydrodynamic wave forces are computed for various sea states. The aim of this study is to argue an interpretation of using *BN* for marine structural reliability analysis in terms of extreme condition scenario and allocate it as a tool for future research on interdisciplinary study for structural reliability analysis, system failure detection, human error estimation and decision making. This will enable the risk assessment to improve the safety of the offshore structures' operation during their lifetime. The framework enables robust reliability updating for determining the best design point of the maximum excursion in the mooring line. By robust it is understood that the reliability updating can be performed in an automated manner using the developed BN. That is, the performance of the structure itself is employed to estimateing the reliability of the structure that encounters sea environments such as wave components. In brief, the conceptual framework, the scope of the study in each section of Environment, Hydrodynamics, Reliability and Failure model is shown in Fig. 1. The