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A simplified method for reliability- and integrity-based design of engineering systems and its application to offshore mooring systems

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A B S T R A C T

This paper presents a simplified method for the reliability- and the integrity-based optimal design of engineering systems and its application to offshore mooring systems. The design of structural systems is transitioning from the conventional methods, which are based on factors of safety, to more advanced methods, which require calculation of the failure probability of the designed system for each project. Using factors of safety to account for the uncertainties in the capacity (strength) or demands can lead to systems with different reliabilities. This is because the number and arrangement of components in each system and the correlation of their responses could be different, which could affect the system reliability. The generic factors of safety that are specified at the component level do not account for such differences. Still, using factors of safety, as a measure of system safety, is preferred by many engineers because of the simplicity in their application. The aim of this paper is to provide a simplified method for design of engineering systems that directly involves the system annual failure probability as a measure of system safety, concerning system strength limit state. In this method, using results of conventional deterministic analysis, the optimality factors for an integrity-based optimal design are used instead of generic safety factors to assure the system safety. The optimality factors, which estimate the necessary change in average component capacities, are computed especially for each component and a target system annual probability of system failure using regression models that

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estimate the effect of short and long term extreme events on structural response. Because in practice, it is convenient to use the return period as a measure to quantify the likelihood of extreme events, the regression model in this paper is a relationship between the component demands and the annual probability density function corresponding to every return period. This method accounts for the uncertainties in the environmental loads and structural capacities, and identifies the target mean capacity of each component for maximizing its integrity and meeting the reliability requirement. In addition, because various failure modes in a structural system can lead to different consequences (including damage costs), a method is introduced to compute optimality factors for designated failure modes. By calculating the probability of system failure, this method can be used for risk-based decision-making that considers the failure costs and consequences. The proposed method can also be used on existing structures to identify the riskiest components as part of inspection and improvement planning. The proposed method is discussed and illustrated considering offshore mooring systems. However, the method is general and applicable also to other engineering systems. In the case study of this paper, the method is first used to quantify the reliability of a mooring system, then this design is revised to meet the DNV recommended annual probability of failure and for maximizing system integrity as well as for a designated failure mode in which the anchor chains are the first components to fail in the system.

1. Introduction

The extensive costs and damages induced by the 2010 oil spill in the Gulf of Mexico as well as other offshore failures during recent years have intensified the efforts to improve the reliability and integrity of offshore systems. The relatively high rates of offshore failure are more than what is considered acceptable, which implies a need for improved methods for better safety of current and future offshore structures. For example, more than twenty-three permanent mooring systems have failed since 2000; 1500 mooring lines were either repaired or replaced. The damage cost of a single mooring failure event was approximately $1.8 billion [1]. The costs of loss of lives or damages to the environment cannot be quantified. As offshore drilling and production sites move to deeper and more challenging environments, the safety of offshore systems becomes even more important, demanding technology development that accounts for their inherent uncertainties. In response, the design methods seem to be in a transition from the conventional methods, which use factors of safety (FoS), to more advanced methods, which include the system reliability and risk assessments.

The simplicity of using FoS to account for the uncertainties has made their application favorable to many engineers; however, as highlighted by the API RP 2SK [2], several studies have shown that the current design practice results in systems with inconsistent failure probabilities, and thus, reliabilities. It is because the safety of a system does not solely depend on the FoS of its components. In turn, structural reliability methods can be used to design an offshore system for a target probability of failure. The DNV OS E301 [3] already facilitate the application of structural reliability methods for design of mooring systems by providing a target annual probability of failure, as an alternative to its FoS-based method; however, such application requires practical methods that are feasible using the available data and decent amount of engineering and computing resources. Developing simplified methods that can quantify and target the offshore system reliability is an important step toward the successful advancements in offshore engineering, including the design of offshore mooring systems.