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Uncertainties Propagation within Offshore Flexible Pipes Risers Design

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Abstract

Flexible riser systems offer operators a robust method of producing oil and gas fields in harsh environments. Systems are currently designed using a mixture of local and international standards such that they can withstand conditions with a sufficient margin of safety. Flexible pipes have been installed for water depth exceeding 2500m. The application of reliability methods to determine the design of offshore systems such as jackets and ship hulls is well developed and has a long and successful track record. Flexible risers are subjected to the same random environmental loads. While probabilistic methods have been explored, they have yet to be applied in any meaningful manner to the fatigue limit state.

How to account in the most robust manner for uncertainties within the loading has become critical for deriving cost effective and robust design rules for flexible risers. Especially the layer of the flexible riser bearing the tensile load, named tensile armours, is critical in the design in many of the deep-water developments. In this paper, multiple structures designed for west of Africa and the North Sea are investigated through a reliability method. Typical Uncertainties within the global riser motions, the local stress computations and in the stress-life curve resistance are accounted for. Demonstration is made that for the same uncertainties the variables influencing the reliability of the structure differ. Finally, the comparison with actual international design rules is made through the value of the safety factor applied on the design life.

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1. Introduction

Flexible riser systems are a robust method of producing oil and gas fields in a range of locations. Often, these locations are most economically developed using a floating production vessel with flexible risers linked to the subsea infrastructure. Many applications are in locations which experience harsh environments and high seas like West-of-Shetland, South Atlantic or Offshore Canada. Designing flexible riser systems to withstand these conditions with a sufficient margin of safety while still making them economically viable remains a challenge.

Flexible riser systems are currently designed using a mixture of local and international standards [1, 2]. Once an initial geometry has been determined, fatigue dynamic analysis using proprietary finite element analysis codes and models (e.g. [3]) is performed. An agreed, between operator and manufacturer, deterministic load case matrix over the scatter diagram is used. For this specific failure mode, uncertainties in the resistance side are accounted for using validated fatigue curves established based on international standards such as ASTM E739-10 [4]. The low frequency, wave induced, fatigue limit state may govern the design of flexible pipe for harsh environments or accidental loading conditions (e.g. flooded annulus). The current design rules allow room for optimization as illustrated in [5] where lower safety factor where demonstrated to contain a sufficient safety margin. These methodologies follow an approach developed for steel riser under medium frequency vortex induces vibrations [6]. These methodologies may also be used to understand the impact of uncertainties during fatigue reassessment for life extension where some historic information on the loading is available [7].

To allow optimization for all types of flexible pipes (production, water injection or export line) in a multitude of sea environments and floating units, the design should assess how the uncertainties propagate throughout the design models. Indeed, the fatigue behavior of the flexible structure varies greatly within the different configurations. This is covered within the physical model, however the current understanding of the impact of the inputs dispersion, on the fatigue predictions is limited. Specifically, the influence of loading uncertainties and not only resistance dispersion, which is characterized experimentally in the fatigue curves, should be further investigated. Furthermore, the pipeline design shall be based on potential failure consequence. This is covered by the safety class that depends on the location of the flexible pipe and the fluid transported by the flexible pipeline. Full structural reliability methods are not the objective as the design process should be kept as efficient as possible, they are however a mean to derive optimized design criteria.

Specifically, this paper is organized as follows. In Section 2, constituents of the unbonded flexible pipe are introduced followed by the current deterministic design methodology related to fatigue limit state. Section 3 presents the structural reliability analysis used in this paper and the safety philosophy on which it is based. We are then in position to apply the methodology on two project cases in the North Sea and West of Africa and evaluate the impact of the flexible configuration on the propagation of uncertainties (Section 4).

Nomenclature

d	Deterministic damage
D	Damage random variable
C	Curvature of the flexible riser
i	Index of the bin in the rainflow-counting algorithm
T	Tension of the flexible riser
σ_a	Alternate stress
σ_m	Mean stress
X	Vector of random variables