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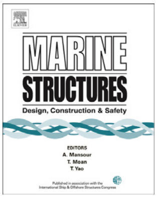

Optimization of composite catenary risers

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ABSTRACT

The use of composite risers may offer important advantages over the use of conventional steel risers in deepwater oil fields. However, the design of laminated composite risers is much more complex than the design of steel risers, due to the large number of parameters that need to be chosen to define the riser layup. This work presents a methodology for optimum design of composite catenary risers, where the objective is the minimization of cross-sectional area of the riser and the design variables are the thickness and fiber orientation of each layer of the composite tube. Strength and stability constraints are included in the optimization model and multiple load cases are considered. The methodology can handle both continuous and discrete variables. Gradient-based and genetic algorithms are used in the computer implementation. The proposed methodology is applied to the optimization of composite catenary risers with different water depths, liner materials, and failure criteria. The numerical examples show that the proposed methodology is very robust.

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1. Introduction

The depletion of existing reserves and the increasing demand for oil and gas have led to the search for deepwater fields and research in new technologies to make the production feasible. Fiber reinforced composite materials present several advantages for offshore applications, such as high specific strength and stiffness, high corrosion resistance, low thermal conductivity, excellent damping properties, and high fatigue resistance.

These favorable properties have motivated the oil industry to use composite materials in different offshore applications [30], including risers [22,29,32,34] and stress joints [21]. The reduced weight obtained by the use of composite risers in replacement to steel risers can be substantial, leading to a significant reduction of top tension requirements, which allows the use of simpler and smaller tension mechanisms and smaller platforms [22,30,34].

This work addresses the use of Composite Catenary Risers (CCR) as an alternative to Steel Catenary Risers (SCR) for deepwater fields. The design of laminate composite structures involves a large number of parameters, including the number of layers and the material, thickness, and fiber orientation of each layer. Thus, the use of the conventional trial-and-error strategy is not adequate and optimization techniques have been widely used in the design of laminated composite structures [15].

The use of optimization techniques in the design of marine risers is recent, but the number of applications has been steadily growing. Different optimization algorithms as Sequential Quadratic Programming (SQP) [18], Simulating Annealing (SA) [35], Artificial Immune Systems (AIS) [37], and Particle Swarm Optimization (PSO) [25] have been used for SCR design. Genetic Algorithms (GA) have also been used in the design of SCRs in free hanging and lazy wave configurations [19,35,37,40], since they are very robust, easily deal with discrete variables, non-continuous and non-differentiable functions, and avoid getting trapped by local minima.

This work presents a methodology for optimum design of Composite Catenary Risers in free hanging configuration. The design variables are the thickness and fiber orientation of each layer. The objective is to minimize the cross-sectional area of the riser joint, considering strength and stability constraints. It is important to note that to the best of the authors' knowledge this is the first work dealing with optimization of composite catenary risers.

This paper is organized as follows. Section 2 presents the main components of composite riser joints and discusses the design of composite risers. Section 3 addresses the structural analysis of composite catenary risers and Section 4 describes the optimization model, including the design variables, objective function, and constraints. Section 5 presents the numerical examples. Finally, Section 6 presents the main conclusions.

2. Composite catenary risers

Composite risers are assembled using a series of joints connected to each other by appropriate connections. Riser joints can have short lengths (10–25 m), intermediate lengths (100–300 m), or long lengths (>300 m) [24]. Top tensioned composite risers for drilling and production generally use short joints, but intermediate and long joints may be better suited for catenary risers. There is also potential for the development of spoolable composite risers without intermediate joints, simplifying the transportation and installation [28]. Composite riser joints are composed generally by three elements: liner, composite tube, and terminations [2,23].

The liners are responsible for fluid containment, ensuring the tightness of the riser and avoiding leaking and loss of pressure. These elements are necessary since composite materials are porous and may have micro-cracks. Most composite joints have an inner and an outer liner. Inner liners can be elastomeric, thermoplastic or metallic. In the selection of the inner liner material, in addition to fluid tightness, other aspects should be observed, as cost, adhesiveness to composite and metallic termination, abrasion and corrosion resistance to the reservoir fluid, and impact resistance to mechanical tools inside drilling risers [2,23,34]. The inner liner can also be used as a mandrel during the composite tube manufacturing. The outer liner is constituted generally of synthetic rubber or thermoplastics. In addition to sea-water containment, the outer liner is responsible for protection against external impact and gouging [17,23]. An additional external layer may be used as a mechanical protection from impacts during transportation and handling.