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Parametric analysis of an offloading hose under internal pressure via computational modeling

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ABSTRACT

An offloading hose is a complex structure, mainly composed of rubber, cords and steel coil, which is used worldwide for oil production and transport systems such as offloading operations in Catenary Anchor Leg Mooring (CALM) buoy. The cords play a vital role on the hose, being responsible for resisting to the applied internal pressure. In this work, finite element models with axisymmetric and 3D elements have been developed to estimate burst pressure of a double carcass floating hose with nominal diameter 20″ and design pressure of 21 bar. Finite element models have been developed in commercial software using reinforcement bars (rebars) to represent cords behavior. A parametric analysis has been performed, and mesh convergence was also evaluated to predict stress concentration in the failure regions. In addition, complex non-linear calculations for the contact between the hyperelastic rubber, which was modelled with Arruda-Boyce's, and the polyester, polyamide and hybrid reinforcement cords, modelled with Marlow's theory, were considered in the FEM. Maximum load in the REBAR layers was used to predict failure in the cords. Actual full-scale experiments were carried out for comparisons, prototypes with different number of layers and cord material have been manufactured. Burst pressure tests of the carcasses was the criterion used to evaluate the minimum requirements of the Oil Companies International Marine Forum (OCIMF). A maximum deviation of 7.5% was found between computational predictions and experimental results. Therefore, the proposed computational model was considered suitable to be used in the design of these hoses, especially for parametric analysis.

1. Introduction

Flexible pipes are used in a variety of applications and may be classified into unbonded and bonded flexible pipes, being both comprised of reinforcements embedded into a flexible polymeric matrix, which is usually an elastomer [1,2]. There are

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several types of unbonded flexible pipes, such as flexible risers where different layers of steel, which constitute the reinforcement, move independently, sliding on anti-wear strips. On the other hand, bonded flexible pipes have reinforcements embedded into a polymeric matrix, such as for offloading hose. In the last case, reinforcements and matrix work as cord/rubber composites. The major difference between flexible risers and hoses is that the former is designed to have high strength to external pressure and compressive stress, whereas for the latter these characteristics are not particularly relevant [3].

The main parts of an offloading hose with double carcass used in the oil sector are shown in Fig. 1. Each carcass has a specific function, leading to different approaches for designing and construction. The typical constituents of the inner carcass are liner, reinforcement and coil, while the outer carcass is typically composed of a second liner and an assembly of reinforcements [2]. Double carcass hoses are built with two independents carcasses as a fail-safe design methodology. Thus, if there is rupture of the inner carcass, the outer carcass prevents oil leakage, allowing safe oil transfer [1,4]. The hose studied in this work has steel end fittings (nipples), which are used for connection with other hoses to yield a hose line. The body layers are usually attached to the nipples by chemical adhesion. The region between body layers and nipple presents severe stiffness transition and high stress concentration and shoulder plies are strategically used to reduce that effect.

The cords are polymeric materials, such as polyamide or polyester. The cords are inserted as fabrics into the butadiene-acrylonitrile elastomer (NBR), producing an elastomeric composite structure with good flexibility and high strength. The angle of the cords relative to the longitudinal axis of the hose influences its axial, flexural and torsional stiffness, as well as the internal pressure strength. The hose must be produced with a certain number of layers or plies to achieve the minimum strength specified by OCIMF 2009 and API 17k. The API 17k defines design methodology and criteria. And according to OCIMF 2009, the inner carcass must be subjected to an internal pressure of five times the rated working pressure over a period of 15 min without showing failure. And after failure of the inner carcass, pressure in the outer carcass must be raised to two times the rated working pressure over an extra period of 15 min.

There are different methods to assess the behavior of flexible pipes. Gu et al. [5] showed an analytical model to forecast strains and stresses in the layers. Alfano et al. [6] developed constitutive laws to predict strains and stresses. A theoretical model was developed by Martins et al. [7] to predict structural behavior of interlocked carcass subject to radial loads. Sævik [8] compared the results from analytical and experimental models. Zhang et al. [9] presented theoretical and numerical study on bending properties, and Ramos Jr and Kawano [10] studied the structural response of flexible pipes when subjected to axisymmetric loads. Also, Souza et al. [11] developed a three-dimensional finite element model with geometrical simplifications, which did not considered nonlinearities to minimize computational cost.

It is not common to find in the literature numerical models that predict more realistic behavior of flexible pipes, including non-linearity behavior, such as buckling phenomenon [12], burst pressure [13] and wet collapse resistance [14]. Besides, residual stress in the wire induced by the manufacturing process of the pipe may also be taken into account, as shown by Fernando et al. [15]. These models may predict the behavior of unbonded flexible pipes, but cannot be directly applied to bonded flexible pipes such as offloading hoses. Loveit and Often [16] developed an analytical methodology for the calculation of unbonded and bonded flexible pipes, describing a linear relationship between load and deflection and using kinematics compatibility and balance of load. Regarding elastomeric composite structures, Pidaparti [17] used a three-dimensional beam finite element model to investigate the mechanical behavior of two-ply cord/rubber laminate subjected to tensile and torsional loadings. Recent studies [18–20] applied similar methodology, and the structural behavior is based on the stiffness matrix, which is calculated using orthotropic elastic properties.

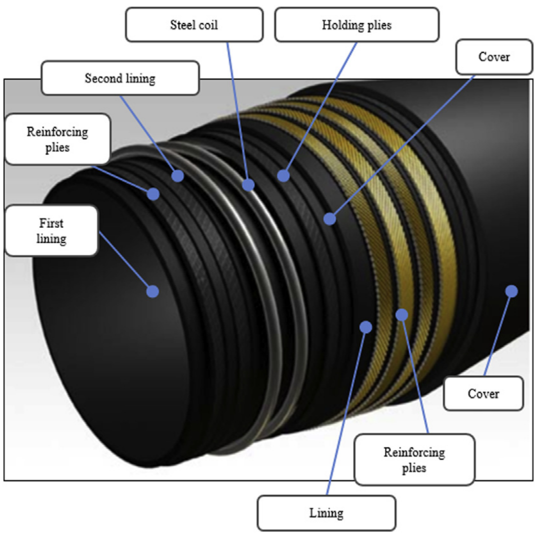

Fig. 1. Bonded flexible pipe for liquid transport [1].