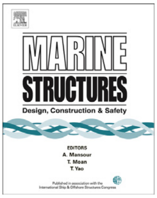
Marine Structures 42 (2015) 95–114

Contents lists available at ScienceDirect

Marine Structures

journal homepage: www.elsevier.com/locate/marstruc



Local structural analysis of flexible pipes subjected to traction, torsion and pressure loads

Roberto Ramos Jr. [*], Alexandre Kawano

Escola Politécnica, University of São Paulo, Av. Prof. Mello Moraes, 2231, São Paulo, SP 05508-970, Brazil

A R T I C L E I N F O

Article history:
Received 28 August 2014
Received in revised form 8 January 2015
Accepted 9 March 2015
Available online 21 April 2015

Keywords:
Flexible pipes
Risers
Marine cables
Axisymmetric loading

A B S T R A C T

Helically armored cables or pipes find a wide range of applications as structural members in engineering. An example of this is the increasing use of flexible pipes in the oil offshore production. Although keeping a geometrical similarity with other helically armored structures such as wire ropes and ACSR conductors, and borrowing from them a useful methodology for the structural analysis, some care must be taken in order not to indiscriminately use an approach which was not thought for a flexible pipe: internal and external pressures, for instance, are a great concern in the analysis of flexible pipes, but obviously not for wire ropes. This work aims at giving some additional contribution to the structural response of flexible pipes when subjected to axisymmetric loads, including the effect of both internal and external pressure in pipe displacements. Derivation of linear operators, relating the stress-resultants to their related displacements or deformations in each of the layers of the pipe, as well as the process of deriving an analogous linear operator to represent the behavior of the pipe as a whole, are clearly presented, highlighting interesting mathematical aspects and their associated physical meaning. A numerical case study of a 2.5″ flexible pipe subjected to traction and internal pressure is also presented and discussed.

---

[*] Corresponding author. Tel.: +55 (11) 3091 5685; fax: +55 (11) 3813 1886.
E-mail addresses: rramosjr@usp.br (R. Ramos), akawano@usp.br (A. Kawano).

http://dx.doi.org/10.1016/j.marstruc.2015.03.004

1. Introduction

Helically armored structures have been used in several applications in engineering. Some examples illustrating the wide use of these structural elements can be found in the offshore industry (flexible pipes and umbilical cables), in the electrical industry (power transmission lines, electromechanical and communication links, submarine cables), in the civil engineering industry (cables for suspension bridges, wire ropes) and in the mining industry (steel cable belts for belt conveyors). Particularly, the design of flexible pipes for the offshore industry has benefited to a great extent from studies of similar helically armored structures such as wire ropes (see, e.g, Knapp [1], McConnell and Zemke [2], Lanteigne [3], Ramsey [4,5], Sathikh et al. [6] and Costello [7]). However, despite keeping some geometrical similarities with flexible pipes, some care must be taken in order not to use exactly the same equations derived for one kind of structure for the other, since they are not subjected to the same loadings (internal and external pressures, for instance, are a concern in the analysis of flexible pipes, but not for wire ropes). In addition to that, some of the modeling hypotheses assumed for wire ropes are not quite appropriate for modeling flexible pipes: radii variations in the analysis of wire ropes, for instance, are often disregarded in order to simplify the modeling; but using materials with low elasticity moduli (polymeric layers) in the fabrication of flexible pipes turns this hypotheses inadequate in the analysis of this kind of structure.

Concerning the structural analysis of flexible pipes subjected to axisymmetric loads, several researchers made their contribution to this field (see, e.g., [8–16]). The aim of this paper is to provide some additional contribution to the local structural analysis of flexible pipes when subjected to axisymmetric loads but, differently from usual related works that consider just traction and torsion loads, this analysis will also discuss the influence of internal and external pressure loads in the related displacements or deformations. In fact, some papers that deal with this kind of loading (e.g., Custodio and Vaz [12], Ramos and Pesce [13] and Sævik and Bruaseth [14]) do not present the full linear operator that incorporates the coupling terms related to the stress-resultants (including the internal and external pressure effects). To the best of the authors' knowledge there are no papers that present a clear formulation of the effects of internal and external pressures on the elements of the matrix that represents the linear operator relating stress-resultants to pipe deformations. Here, a clear derivation of linear operators relating the stress-resultants in the cross-sections to their related displacements or deformations in each of the layers of the pipe as well as the process of deriving an analogous linear operator to represent the behavior of the pipe as a whole are presented, showing some interesting mathematical aspects and their associated physical meaning. A numerical case study of a 2.5″ flexible pipe subjected to both traction and internal pressure is also presented and discussed, in order to show the applicability of the method.

2. Working hypotheses

As mentioned previously, the loadings considered in the current analysis include: traction, torsion and internal and external pressures. The initial (unstressed) length L_0 taken for the pipe segment is irrelevant but, for practical purposes, it can be assumed to have an order of magnitude such that $O(L_0/D) \cong 10$, where D stands for the outside diameter of the pipe. In this case, the stress-resultants in each of the "extremities" of the pipe segment do not vary appreciably. For the sake of completeness, all the hypotheses considered in the mathematical modeling (to be presented in the forthcoming sections) are outlined below. They are: 1) All layers at all cross-sections present the same twist per unit of pipe length and the same elongation; 2) No gap between adjacent layers is allowed in the unstressed (initial) state; 3) There is no contact between adjacent tendons in the same helical layer, whatever the configuration; 4) All materials are homogeneous, isotropic and have linear elastic behavior; 5) All strains are small if compared to unity (i.e., the geometric linearity hypothesis applies); 6) No kind of imperfection in the circularity of the layers is considered (i.e., all layers are circumscribed to perfect cylindrical regions whose inner and outer radii depend on the loading conditions); 7) Thickness variations in the layers are assumed to be uniform in each layer; 8) The stress state for the tendons of the helical layers is composed of only normal stresses acting respectively in the tangent and normal