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Structural response of a flexible pipe with damaged tensile armor wires under pure tension

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ABSTRACT

This article studies the structural response of a 6.0” flexible pipe under pure tension considering intact and damaged conditions. In the damaged condition, several wires of the tensile armor layers are assumed to be broken. A three-dimensional nonlinear finite element (FE) model devoted to analyze the local mechanical response of flexible pipes is employed in this study. This model is capable of representing each tensile armor wire and, therefore, localized defects, including total rupture, may be adequately represented. Results from experimental tests validate the FE predictions and indicate a reduction in the axial stiffness of the pipe, a non-uniform redistribution of forces among the remaining intact wires of the damaged tensile armor layers and high stress concentrations in the wires near the broken ones. Moreover, the FE model indicates that significant normal bending stresses may arise in the pressure armor and inner carcass due to an uneven pressure distribution on these layers. Finally, the results obtained are employed to estimate the pull out capacity of the studied flexible pipe.

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1. Introduction

Unbonded flexible pipes, as shown in Fig. 1, are key components of offshore oil and gas applications as production, gas lift or gas and water injection lines. They are composite structures that comprise several steel and plastic concentric layers designed to meet specific requirements. The polymeric layers work as sealing, insulating and/or anti-wear components, whilst the metallic layers withstand the imposed structural loads. There are basically three different types of metallic layers in these structures [3]: the inner carcass, which is made from profiled stainless steel strips wound at angles close to 90° and is designed to sustain radial inward forces; the pressure armor, which is usually made from Z-shaped carbon steel wires wound at angles close to 90° and supports the system internal pressure and also radial inward forces; and the tensile armor layers, which are typically constituted of several rectangular shaped carbon steel wires laid in two or four layers, cross-wound at angles between 20° and 55°, and are designed to resist to tension, torque and pressure induced effects.

As a result of its manufacturing process, the tensile armor wires have hard and textured micro-structure and are also prone to the occurrence of small marks and pits that can cause crack nucleation [11]. Therefore, crack propagation mechanisms in these wires are analogous to those observed in fragile materials and failures occur once the flaw size is reached [11]. According to the API RP 17B [3], however, the integrity of the tensile armor layers has to be ensured during the entire service life of a flexible pipe, because the rupture of their wires significantly reduces the structural capacity of the pipe leading to its premature failure.

In the last few years, a number of inspection and surface in-field monitoring techniques have been proposed and developed aiming at monitoring the tensile armor layers of flexible pipes. API RP 17B [3] indicates that visual inspections and periodic pressure tests are commonly used, but non-destructive techniques (NDT) relying on readings from optical fibers and acoustic emissions sensors [21] or on acoustic emissions associated with other NDT techniques [11] are promising approaches that could instantly detect the rupture of a wire, even in sections of the pipe in which a visual inspection could not be performed.

Once the rupture of a wire in a tensile armor layer is detected, the repair of the pipe is required. Anderson et al. [1] have recently described the in-service repair of a gas export flexible pipe with 15 wires broken in its tensile armor layers. This procedure typically involves retrieving the pipe at the location, removing its damaged section, installing new end fittings and putting it back in operation. The operation of retrieving a flexible pipe is called *pull out* and is performed by a PLSV (Pipeline Laying Support Vessel) [23] using one of the methods schematically shown in Fig. 2. In the first method, the pipe (riser) is firstly disconnected from the floating production facility and, after that, from the subsea

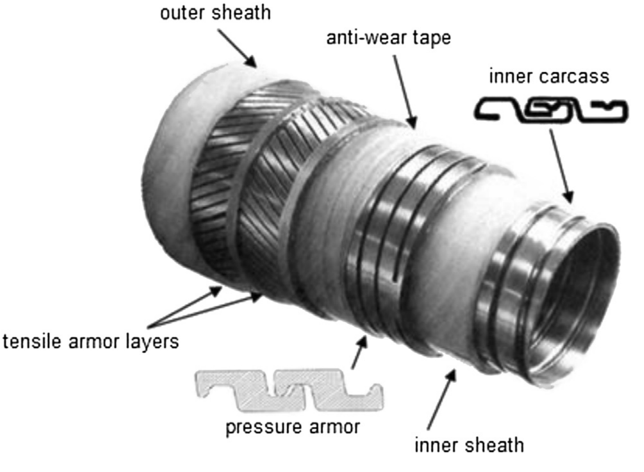

Fig. 1. Typical unbonded flexible pipe.