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Fatigue Life Assessment of Reeled Risers

Theodoro A. Netto, Marcelo I. Lourenço, and Adriana Botto, Universidade Federal do Rio de Janeiro

Abstract

One of the most effective installation methods of metallic risers is the reel-lay process, in which pipe segments are welded onshore and subsequently bent over a cylindrical rigid surface (reel) in a laying vessel. During installation, the line is unreeled, straightened, and then laid into the sea under tension. In this process, material properties change and eventual weld defects may increase, thus reducing the fatigue life of those joints under operational loads. Therefore, welded joints must be manufactured based on strict weld acceptance criteria. These criteria shall guarantee reliable standards regarding the fatigue life of the joints while not impairing the feasibility of weld manufacture (high cost). In this work, the reeling process is initially simulated through a nonlinear finite element model that incorporates weld defects. The results are then used as guidelines to experimentally obtain fracture mechanics parameters of typical weld under pre-strained conditions. The fatigue life of as-welded and reeled joints with different defects (lack of fusion and lack of penetration) are subsequently estimated via a finite element model that accounts for the changes in the material properties due to prestraining.

Introduction

The most efficient and cost-effective method of pipeline installation involves pipe onshore welding and pipeline bending over a rigid circular surface on the vessel. During offshore installation, the pipeline is straightened and launched under tension into the sea. These methods have been successfully used in Brazil for installing pipelines up to 1,300 m (approximately 4,300 ft) water depth.

However, the bending, unbending, and straightening processes as applied on the vessels induce the pipe to bending-curvature histories, which are well into the plastic range of the material (e.g. Odegard et.al (1998)). Although the pipe is straightened prior to launch, distortions in the form of residual out-of-roundness, residual stresses, changes in material properties due to plasticity, and growing of eventual welding flaws may occur. These effects may have an influence in both the ultimate strength and subsequent fatigue performance of the line. Thus, in addition to ultimate strength design, the use of steel catenary risers (SCR's), which will be inevitably subjected to cyclic loading during operation, implies in a careful examination of the possibility of riser failure due to fatigue. In this context, the influence of installation methods involving pipeline material and geometric changes must be taken into account in the evaluation of the riser structural integrity during its operational life.

Fatigue life predictions based on S-N curves and fracture mechanics approaches can be employed in the preliminary stages of the design. Nevertheless, the necessary confidence to establish a consistent planning for SCR's installations using reel methods should be built upon laboratory fatigue tests using full-scale pipes and realistic girth welding processes. A test program including reeling simulation and fatigue tests on pipes with outside diameters (D) of 8.625 in and girth welds with induced lack of fusion and lack of penetration defects has been recently carried out at COPPE/UFRJ as part of a research project involving PETROBRAS and mostly funded by the Brazilian Governmental Financial Agency FINEP.

The results obtained from the reeling experiments were first used to calibrate a three-dimensional nonlinear finite element model. The model was then used to perform a series of calculations considering those two types of defects with different geometries. Guided by the experimental observations, attention was focused on the localized deformation that occurs in the vicinity of the defects during reeling. These results served as guidelines for the development of laboratory tests for determining fracture mechanics properties of raw and pre-strained test specimens made of typical weld. These include the resistance and da/dN curves. Finally, the fatigue lives of as-welded and reeled joints with different defects are calculated. A refined finite element model was developed with this purpose. The changes in the material properties due to pre-straining are incorporated in the analyses in order to verify their detrimental effect on the fatigue life of reeled pipes.

Experiments

The series of experiments on pipes of the material API 5l X60, with 8.625 in (2.08mm) external diameter, 0.593in (15.06mm) of thickness, 5.2m of length was described by Netto, Lourenço and Botto (2004) were used as a base case to develop the numerical analyses performed.

During manufacture, different discontinuities such as lack of fusion and lack of penetration (henceforth denominated LF and