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Reliability Analysis of Flexible Riser Systems

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ABSTRACT

Design formats for flexible pipes are briefly reviewed. A procedure for case-by-case reliability assessment of specified failure modes for flexible riser systems is outlined. Application of this analysis tool is illustrated for three different combinations of surface vessel/riser configuration. The ultimate limit states considered are top end tensile failure, excessive curvature at the hog bend, and axial compression at the sag bend. For these potential failure modes, the various sources of uncertainty are identified and quantified. Based on this input, relations between safety factors and failure probabilities are determined in each case.

INTRODUCTION

At present, design of flexible risers is typically based on a permissible stress format utilizing a single safety factor. Due to the wide application range for flexibles, the reliability level implied by such a format will be significantly different for various types of riser systems. A possible improvement can be achieved by introducing design formats based on partial load and resistance coefficients that are individual for each type of load effect. In particular, formats aiming at uniform utilization of individual pipe layers will be optimal. This applies to separate as well as combined load conditions (e.g., tension and torsion).

Regardless of which design format is being used, there is an urgent need for assessment of the level of safety corresponding to a given set of safety factors or partial coefficients. Obviously, the main interest is in situ conditions rather than idealized laboratory conditions. Nondestructive testing (e.g., pressure testing) may provide some information in this respect. Full-scale measurements can serve to verify and improve computational models and procedures. However, a framework representing all relevant uncertainties will be required in order to make a systematic assessment possible. Such a framework also makes it possible to incorporate new information obtained from laboratory experiments, full-scale measurements and testing as well as monitoring.

In this paper, the various sources of statistical uncertainty are considered. A procedure for calculation of reliability measures for a given failure mode and a given riser system is subsequently outlined. It is assumed that information quantifying the randomness related to each source of uncertainty is available. The so-called failure functions are determined by specifying failure criteria corresponding to individual pipe layers. These criteria are obviously different for various types of failure modes.

It is illustrated how this approach permits reliability assessment on a case-by-case basis for three different riser systems. For the failure modes considered, relations between safety factors and failure probabilities are determined. A target value of annual failure probability equal to 10^{-4} is employed as a reference value (Jiao, Leira and Moan, 1990).

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The design formats discussed above are reviewed in the next section. These formats are general, and they apply to the flexible pipe as well as bending stiffeners or other pipe components. However, in the subsequent example studies, focus will be on ultimate limit state failure modes for the pipe itself.

DESIGN FORMATS

There are several standards and guidelines for the design and operation of high-pressure pipes, for example, NPD (1990), API (1988) and Veritec (1987). Only the API and Veritec guidelines address flexible pipes explicitly. In addition, various oil companies have issued design specifications for internal use.

Permissible Stress Format

The general content of these documents regarding design considerations are essentially the same, being based on the permissible stress method. The corresponding design format is given as:

$$S_c \leq R_c/SF \qquad (1)$$

where S_c is the characteristic load effect for the actual loading, R_c is the characteristic resistance for the considered failure mode, and SF is the corresponding safety factor accounting for all uncertainties in loads, resistance, analysis methods, etc. Two load effect contributions are generally considered by the permissible stress method:

- functional loads
- external environmental and simultaneously acting functional loads

The *design environmental loads* for the operation phase are to be the most probable extreme load with a return period of 100 years for the actual location.

The flexible pipe is to be designed to resist the applied loads and prevent the following failure modes:

- burst failure (internal pressure)
- tensile failure
- axial compression failure
- buckling due to hydrostatic pressure and radial loads (external pressure)
- torsional failure
- bending failure
- excessive leakage