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Optimal Design-Phase Inspection and Replacement Planning of Pipelines Subjected to CO_2 Corrosion

Svein Gunnar Hellevik
Aker Offshore Partner AS, Stavanger, Norway

Ivar Langen*
Stavanger University College, Department of Mechanical Engineering and Materials Science, Stavanger, Norway

ABSTRACT

A methodology for cost optimal reliability-based inspection and replacement planning of pipelines in the design-phase is described. The degradation mechanism considered is CO2 corrosion. The methodology is based on the application of methods for structural reliability analysis within the framework of Bayesian decision theory. The planning problem is formulated as an optimization problem minimizing the expected lifetime costs with the minimum acceptable reliability level as a constraint. The optimization parameters are the nominal design wall thickness, the number of inspections in the expected lifetime, the time intervals between inspections and the inspection method to be used.

INTRODUCTION

Submarine pipelines are among the critical components of offshore installations. Pipeline failures commonly have significant economic implications for the operator in terms of lost production and replacement/repair. Failures may also constitute serious hazards in case of leakage. Due to the serious consequences, inspection and maintenance activities are regularly carried out in order to secure the continued integrity and to meet regulatory requirements. The costs associated with these activities constitute a significant portion of the total operational costs of offshore installations.

This paper presents a methodology for cost optimal reliability-based inspection and replacement planning of pipelines in the design phase. The methodology is based on application of methods for structural reliability analysis within the framework of Bayesian preposterior decision theory. Through application of the theory for Bayesian preposterior decision analysis, a consistent framework for evaluation of the (uncertain) consequences of different inspection and replacement plans is provided. Thus, expressing the consequences in monetary values, the inspection and replacement plan which provides the lowest expected costs in the expected lifetime can be selected. The potential of structural reliability methods as decision support tools in engineering application is due to the consistent modeling of uncertainties.

The pipelines considered in this paper are made of carbon steel and carry unprocessed hydrocarbons. In such pipelines, carbon dioxide (CO_2) corrosion is one of the most significant degradation mechanisms. CO_2 corrosion is controlled by many parameters with significant variation and uncertainties. Consequently, the prediction of CO_2 corrosion rates and the prediction of the residual strength of corroded pipes are uncertain. This fact makes use of structural reliability methods very attractive.

Even though corrosion attacks may extend over larger areas in the longitudinal direction of pipelines, these are typically limited to certain areas being more vulnerable to corrosion than others. Since the pressure and temperature are highest close to the inlet, this part is regarded as critical to corrosion. Other vulnerable parts would be the lower-lying areas of a pipeline, since these are more susceptible to separation and accumulation of the corrosive water phase and subsequently to corrosion attacks. The parts of a pipeline where the most severe corrosion attacks are expected to occur are here referred to as segments.

Two damage modes are considered, i.e. pitting and longitudinal grooving corrosion. If a pit penetrates the wall thickness, the resulting failure mode is pinpoint leakage. The resulting failure mode due to longitudinal grooving corrosion is bursting, leading to ultimate pipe rupture. Due to stratified flow, both damage modes are confined to the 6 o'clock position.

For inspection of internal corrosion in pipelines, intelligent pigging is definitely the most widely used method today. Intelligent pigs are instrumented vehicles which travel internally along the pipeline, and map the metal loss (or the remaining wall thickness) of its components. If unacceptable corrosion damage is detected in a segment, the assumed maintenance strategy for the pipelines considered here is to replace the segment.

FORMULATION OF OPTIMIZATION PROBLEM AND MODELING OF EXPECTED COSTS

Formulation of Optimization Problem

The aim is to determine a cost optimal inspection and replacement plan which covers the expected lifetime. Since the plan must be established without any knowledge of the actual outcome of future inspections, Bayesian preposterior decision analysis forms a rational basis for this purpose. Bayesian decision analysis is described in Raiffa and Schlaifer (1961) and Benjamin and Cor-

*ISOPE Member.

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