The use of probabilistic fracture assessment procedures in design of pipelines subjected to large strains

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ABSTRACT

Design against fracture in pipeline girth welds deals with hypothetical defects. A logical step would be to apply probabilistic assessment procedures including an assumed distribution of weld flaws. The major part of fracture assessments carried out today is semi-deterministic. Even if such an approach might be applicable, it is proposed that it may not always lead to optimum results in terms of combination of safety level and cost-effectiveness. The risk of girth weld fracture is influenced by several parameters like weld defect size, tearing resistance, weld metal mismatch, misalignment, yield to tensile strength ratio, etc. The likelihood of the most detrimental values of each distribution occurring at the same position is usually very low. Further, fracture assessment of pipelines often requires that the different steps in the loading history are considered in the analysis. In this paper we illustrate how probabilistic assessment can be used to obtain the overall reliability of pipelines wrt girth weld fracture. We discuss statistical representation of the different key input parameters and how the analysis can be used to determine characteristic values to be used in design assessment to meet target reliability levels. Further, we illustrate how the procedure can be used to investigate the significance of previous load steps, such as the effect of installation loads on the strain capacity during operation.

KEY WORDS: Fracture mechanics, strain based design, pipeline engineering.

INTRODUCTION

The field of strain-based design of pipelines, with special focus on tensile strain capacity due to potential defects, has received considerable attention the last 10-15 years. The ISOPE SBD symposium, having its 10th anniversary at this year’s conference, has been one of the main arenas for exchange of ideas in this respect. In this period there has been made significant contributions and developments within the field. An improved understanding of the main physical features controlling pipeline failure has been established, and several models for estimation of tensile strain capacity have been proposed, (see e.g. Østby (2007), Fairchil et al. (2014), Tang et al. (2014), Wang et al. (2012)). As a part of this development, increased use of FEA, both w.r.t. obtaining new knowledge and to development of quantitative models, has taken place (see review paper by Østby (2015)). There have also been several large-scale testing campaigns to validate models, and in general the models have been found to very well reproduce the average trend in the experimental results. It is underlined that there are still uncertain areas, e.g. embedded defects, where there is a need for a better understanding of the phenomena and how to include this in models. However, in general it is fair to say that we are in possession of quite accurate models for assessing tensile strain capacity of pipelines with defects.

However, when it comes to the optimum use of the models in design assessment, there are still open questions and room for even better practices. The problem is complex and involves several parameters. Today most fracture assessments of pipelines are carried out within a deterministic framework. However, the significance of the outcome w.r.t. to overall reliability can be challenging to assess. Further, the impact of different loading scenarios may have to be combined, e.g. installation and operation. The optimum way to do this is far from trivial. Extended use of probabilistic assessment is a natural next step for the development of strain-based design procedures. Probabilistic fracture assessment is not a new idea, and several procedures have been proposed earlier (see e.g. proposal for calibrated safety factors in BS 7910). However, in daily design of pipelines they have not seen a widespread use yet, although virtually all other failure modes are assessed based on the use of target reliability levels and partial safety factors (see e.g. DNV GL ST-F101).

The objectives of this paper is to present a general discussion regarding probabilistic approaches for strain-based fracture assessment of pipelines and present some specific examples of the use of such approaches as a first step towards a more formalized treatment of the topic. The outline of the paper is as follows. First we present a short motivation for the introduction of probabilistic fracture assessment of pipelines, with focus towards design. Then we discuss the probabilistic assessment from a more general point of view, addressing key issues related to input parameters and model uncertainty for strain-based assessment models and some features concerning the statistical analysis scheme. The second part is presenting specific examples. The firs