Proceedings of the Eighteenth (2008) International Offshore and Polar Engineering Conference
Vancouver, BC, Canada, July 6-11, 2008

ISBN 978-1-880653-70-8 (Set); ISBN 1-880653-68-0 (Set)

Effect of embedded defects in pipelines subjected to plastic strains during operation

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ABSTRACT

Recent research has shown that the effect of internal pressure can be detrimental to the fracture response of pipelines with circumferential flaws subjected to bending or tensile loading. In addition, recent work at SINTEF indicates that embedded defects under certain circumstances can be more critical than surface cracks with the same height and length. This is contrary to the common practice in ECA analyses of assuming that the results for surface cracks can be conservatively applied also to embedded defects given that the ligament height (distance from defect to pipe surface) is at least half of the defect height.

Today's analytical equations that are the basis for most engineering critical assessments are not capable of accounting for the effect of internal pressure, and the industry does not have a common recognized practice for assessing the integrity of pipelines for longitudinal strains in the plastic range during operation. Finite element methods, however, can be used to accurately simulate the effect of biaxial loading.

A finite element model with shell and line spring elements that incorporate the effect of internal pressure has been employed to efficiently investigate the fracture integrity of a pipeline during operation. The model is capable of analyzing surface cracks on both the inner and outer pipe surfaces under biaxial loading, as well as embedded defects with various ligament heights. The pipe model has been subjected to tensile loading while under internal pressure, and embedded defects have been compared to surface cracks of similar size. The results illustrate that embedded defects can cause a reduction in the strain capacity as compared to surface cracks.

KEY WORDS: Embedded defects; internal pressure; fracture; strain-based design; tensile strain capacity.

INTRODUCTION

Pipelines may be subjected to high longitudinal strains during installation and service. Offshore pipelines are typically subjected to the highest strains during pipe laying, but strains well into the plastic regime may be experienced also due to lateral or upheaval buckling from high temperature/high pressure during service. Ice gouging and sub-gouge deformation from drifting sea ice may also introduce large strains in offshore pipelines. For onshore pipelines high strains are typically associated with frost heave or thaw settlement for arctic pipelines, slope instability, seismic activity etc.

Today's analytical equations that are the basis for most engineering critical assessment (ECA) procedures have limited applicability when the longitudinal stress exceeds the specified minimum yield stress (SMYS), often defined as the stress when the strain equals 0.5%. These analytical equations are also incapable of accounting for the effect of internal pressure. Recent research on the fracture capacity of pipelines subjected to a biaxial state of stress (e.g. from internal pressure during service) has shown that biaxial stresses significantly increase the crack driving force for pipes subjected to tension (Jayadevan et al., 2004) or bending (Østby et al., 2005). Experimental work that demonstrates this effect has also been carried out (Østby and Hellesvik, 2007). No analytical equations currently in use for ECA application are capable of accounting for the effect of biaxial stress.

Significant work has been carried out in recent years to develop methods to design pipelines for large strain application during installation and service. Some work has also been carried out on tensile strain capacity for embedded defects (Wang et al., 2006), but common to most of the work on the subject is that is has focused on circumferential, surface breaking defects.

There is limited guidance on the treatment of embedded defects subjected to plastic strains. The recommended practice DNV-RP-F108 (DNV, 2006) was developed to extend the limits of traditional analytical equations to provide guidelines for fracture control of pipelines subjected to installation methods that introduce plastic strains. It is noted that this document mainly considers pipeline installation. However, it contains a suggested simplified method for treating embedded defects: If the ligament height is greater than half the defect height, the results obtained for surface cracks can be applied also to embedded defects of similar length and height. For smaller ligament heights the ligament height shall be added to the defect height (recharacterization).