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Fracture Control – Offshore Pipelines JIP
Use of Abaqus/Explicit to simulate ductile tearing in pipes with defects loaded beyond yielding

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ABSTRACT

In this paper three dimensional finite element modeling of pipes with circumferentially oriented surface cracks has been carried out to simulate experiments with combined bend loading and internal pressure. The models are solved using Abaqus/Explicit. Quasi-static solutions were obtained by controlling the loading rates. Ductile tearing is taken into account using the Gurson-Tvergaard-Needleman model, and the constitutive model represents a realistic model for X-65 pipeline steel. In Part I the applicability of the solution method is demonstrated by comparing FEM-simulation results with results from full scale experiments of a pipe in four-point bending, with and without internal pressure. New results from a full scale experiment are also presented. The results show that both the global structural response and the local ductile fracture, are captured in the simulations. In Part II, a parametric study on the effects of defect dimensions and internal pressure, assuming tension loading, is presented. The simulations illustrate how the strain capacity depends on the pressure level, with decreasing strain capacity with increasing internal pressure. Additionally, the strain capacity decreases as the crack depth increases. The effect of crack length in the circumferential of the pipe becomes more important as the crack depth increases.

KEY WORDS: FEM; pipelines; cracks; ductile fracture.

INTRODUCTION

Pipelines may be exposed to large variation of loads, depending on the surroundings and area of application. These loads may result in global deformations well into the plastic region. If a crack is present in a tensile region it may grow and possibly lead to a fracture and collapse. The strain capacity of ductile pipes with defects is limited by the amount of tearing that can be tolerated before the maximum load capacity is reached.

In the Fracture Control - Offshore Pipelines JIP the focus has been on ductile steel materials and the effect of internal pressure. One important part in the project involves small scale and full scale experiments. Full scale experiments are costly and time consuming, but definitely necessary to perform to obtain confidence around numerical calculations, such as nonlinear FEM-models including ductile tearing and different loading conditions. In Part I of this paper, it is illustrated that 3D explicit FEM-models may be a supplement to large-scale testing, in determining the strain capacity of pipes with defects. In Part II of the paper, a parametric study on the effects of defect dimension and internal pressure level is presented, assuming tension loading. These results clearly show the strong effect of the internal pressure level on the strain capacity, with decreasing strain capacity for increasing internal pressure level (up to hoop stress of 50% of yield). The simulations also demonstrate the effect of the crack length in the circumferential directions of the pipe, and it is shown that this parameter becomes more important as the crack depth increases. The presented analyses underline the possible applicability of 3D FE simulations as a tool in strain-based fracture research of pipelines, especially for use in relation to sensitivity studies.

PART I

Full scale experiment

The full scale experiments were performed by SINTEF as a part of the Fracture Control - Offshore Pipelines JIP. Surface cracked pipes in four-point bending with and without internal pressure were investigated. The pipes were from a 12” seamless pipe (X-65 pipeline steel) with outer diameter OD=325 mm and wall thickness of approximately 15mm. Details about the pipes, defect geometries, measuring techniques and experimental setup may be found in Østby and Hellesvik (2007). Three different experiments are presented in this paper, where results from one are presented for the first time. This model is denoted as Test 1. Test 2 and Test 3 are presented in details in Østby and Hellesvik (2007). The pipes have the following data: nominal outer diameter OD, nominal wall thickness t, crack depth a, crack length 2c and internal pressure p_i. The experimental setup and geometry for all the tests are as shown in Figure 1, and additional geometry information and pressure levels are found in Table 1. The crack is modeled as a constant depth defect with end radius equal the