International Journal of Offshore and Polar Engineering (ISSN 1053-5381)
http://www.isope.org/publications/publications.htm

Vol. 25, No. 3, September 2015, pp. 212–220; http://dx.doi.org/10.17736/ijope.2015.oa05

Strength and Deformation Capacity of Corroded Pipe: Laboratory Tests and FEM Analyses

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With the future development of offshore pipelines moving toward difficult operating conditions and deep/ultradeep water applications, there is a need to understand the failure mechanisms and better quantify the strength and deformation capacity of corroded pipelines, considering the relevant failure modes (collapse, local buckling under internal and external pressure, fracture/plastic collapse, etc.). A joint industry project sponsored by ENI Exploration and Production and Statoil has been launched with the objective to quantify and assess the strength and deformation capacity of corroded pipes in the presence of internal overpressure.

INTRODUCTION

In the pipeline industry, much effort has been dedicated to estimating the remaining strength of corroded pipelines against the internal pressure containment (bursting) failure mode. This effort is enclosed in several international standards; see, for example, DNV-RP-F101 (DNV, 2004), ASME B31G (ASME, 1991), BS 7910 (BS, 2005), and API RP 579 (API, 2000). In practice, offshore pipelines also have to sustain external pressure (which drives the wall thickness selection in deep and ultradeep water applications), axial loads, and bending moments with internal and external overpressure induced, for example, by operating pressures and temperature conditions and sea bottom roughness; see, for example, Torselletti et al. (1999), Collberg et al. (2005), and Vitali et al. (2006). The future development of offshore pipelines is moving toward difficult operating conditions: the arctic environment, longer tie-back pipelines under internal corrosive conditions (sometimes sweet, more frequently sour (see Vitali and Bruschi, 2010)), and ultradeep water applications (where the corroded pipelines might be subject to shutdown and shut-in conditions during their operative lifetimes (see Vitali et al., 2010). Thus, there is a need to understand the failure mechanisms and better quantify the strength and deformation capacity of corroded offshore pipelines considering the relevant failure modes, particularly:

- Bursting failure mode (Bu-FM) caused by internal-pressure-dominated load conditions;
- Collapse failure mode (Col-FM) caused by external-pressure-dominated load conditions;
- Local buckling failure mode (LocBuck-FM) caused by bending moment load conditions in the presence of external and internal overpressure and steel axial force;
- Fracture/plastic collapse of defective girth welds under bending moment load conditions in the presence of external and internal overpressure and steel axial force.

Corrosion is defined as a loss of wall thickness due to chemical reactions. Metal loss due to corrosion can occur in the base material, the seam weld, the girth weld, and/or the associated heat-affected zone (HAZ). It can occur on the inside or outside surface of the pipe. Corrosion can have a smooth or an irregular profile and can contain sharp and interacting features that cause a local stress concentration. The behavior of pipelines with corrosion defects is affected by the following parameters:

- Pipe geometry: Steel pipe diameter, OD; Pipe diameter-to-thickness ratio, OD/t; Pipe initial ovalization, O_v.
- Steel material properties: Yield stress, σ_y; Ultimate strength, σ_u; Uniform elongation, UE; Stress–strain relationship (round-shaped or with Lüder plateau); material toughness (relevant for small defect sizes).

Received November 19, 2013; updated and further revised manuscript received by the editors February 6, 2015. The original version (prior to the final updated and revised manuscript) was presented at the Twenty-third International Offshore and Polar Engineering Conference (ISOPE-2013), Anchorage, Alaska, USA, June 30–July 5, 2013.
KEY WORDS: Pipe, local buckling, FEM analysis, experimental tests.