International Journal of Offshore and Polar Engineering (ISSN 1053-5381)

Vol. 18, No. 3, September 2008, pp. 188–195

Langeled: Pipe Capacity vs. Wall Thickness Selection

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The Langeled Pipeline South (LPS) is characterized by a large diameter and thin steel wall, giving rise to an outer diameter-to-thickness ratio, D/t, larger than 45. The local buckling design equation in DNV OS F101 is explicitly defined as applicable to a pipe D/t ratio equal to or lower that 45. It was then necessary to investigate if DNV OS F101 could also be made applicable as a project guideline for $D/t > 45$. The scope of this paper is to present the results of a desk study carried out during the project development; the study aimed to verify the applicability of the local buckling design equations enclosed in DNV OS F101. In particular, the following aspects are discussed in the paper: Finite Element Modeling of the pipe section of the LPS, including weld misalignment and the specified geometric tolerances; 3-dimensional FE Models aiming to analyze the LPS under relevant load conditions; FE calculations and sensitivity analysis aiming to determine the nonlinear loading curve (moment vs. curvature under axial/pressure loads), and to identify the limit bending pipe capacity and the relevant deformations; comparison of the calculated limit bending capacity with the results from the application of the DNV OS F101 design format.

INTRODUCTION

Ormen Lange is a large gas field 120 km off the west coast of central Norway. The field has been developed with 2 subsea templates and two 3-in flowlines to shore at Nyhamna, where a gas treatment facility is being built. Norsk Hydro is the development operator while Norske Shell will operate the field and the plant.

As part of the Ormen Lange development, a 1200-km-long, large-diameter pipeline, Langeled, has been installed from Nyhamna to Easington on the east coast of England. Statoil has managed the Langeled Development Project on behalf of Norsk Hydro. Gassco, as the operator of all gas export pipelines from the Norwegian Continental Shelf, will be the operator of the pipeline.

Langeled is tied into the Sleipner field about midway to England. The northern leg, from Nyhamna to Sleipner, is a 4-in-diameter 250/215-bar pipeline, while the southern leg from Sleipner to Easington is a 44-in-diameter 157-bar pipeline.

The Langeled Pipeline South (LPS) is characterised by a large diameter and thin steel wall, giving rise to an outer diameter-to thickness-ratio, D/t, greater than 45. This followed from the selection of the SAWL485 steel grade, which has allowed a meaningful reduction of the investment costs when market prices for line pipe material had increased tremendously.

The local buckling design equation in DNV OS F101 is explicitly defined as applicable to a pipe D/t ratio equal or lower than 45. This applies to both internal pressure and external pressure combined with bending moment and axial force. A desk study was then carried out in order to assess the strength and deformation capacity of the LPS pipeline, including the bifurcation buckling.

The scope of this paper is:

• To discuss the analysis methodology and the results of the bifurcation buckling analysis.

• To briefly describe the FE model undertaken to analyze the bending capacity of the LPS pipeline under relevant load conditions.

• To show the results of an FE model study carried out to analyze the effect of the relevant parameters, i.e. load combination, pipe geometric characteristics (outer D/t ratio), girth weld parameters (mechanical strength, pipe joint misalignment), etc.

• To compare the limit bending capacity/strain as obtained with the FE model with the limit bending capacity/strain as predicted, using DNV OS F101 design formats.

A commercial computer code environment was used to develop the 3-Dimensional Finite Element (FE) Model (Hibbit, 2000).

Background of Local Buckling Mechanism

Nonlinear collapse/local buckling refers to the decrease in the stiffness of a structure as the load increases. At the collapse (or buckling) load, the load deflection curve has zero slope and the structure becomes unstable if the deformation is load controlled. The load-deflection curve is called the primary or fundamental path; the deformation on the primary path, the primary deformation.

A primary path described by a nonlinear or linear stress analysis of a so-called perfect structure may possess forks or bifurcation points. At the first bifurcation point, a new deformation pattern unexpectedly different from the primary deformation pattern may begin to develop. This is not because of a change in the external load, but because the equilibrium configuration on the primary path is unstable at this point. The resulting deformation pattern is called the bifurcation mode; the associated load deflection curve, the secondary path.

Real structures are imperfect. There are unavoidable minor irregularities in dimensions and material properties (submarine pipelines are ovalised and present thickness variations, weld misalignments, etc.). The imperfections may trigger a primary deformation pattern different from the theoretical one. The bifurcation concept may then be without meaning for real structures. Depending on pipe geometry, mainly outer D/t ratio, and load condition (presence of internal pressure or lack of presence), bifurcation buckling may or may not predict the limit load.

Received January 3, 2008; revised manuscript received by the editors March 20, 2008. The original version (prior to the final revised manuscript) was presented at the 17th International Offshore and Polar Engineering Conference (ISOPE-2007), Lisbon, July 1–6, 2007.

KEY WORDS: Submarine pipeline, local buckling, bifurcation buckling, limit state, failure mode.