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Limit Load Capacity of Thick-walled Pipe in Ultra-deep Water

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Market demand pushes subsea developments into ultra-deep water. Pipelines installed in such environments require very thick walls to cope with the extreme hydrostatic pressure. However, the design criteria for local buckling under combined loading in one of the prevailing submarine-pipeline design standards, DNVGL-ST-F101 (2017), are stated to be valid only for pipelines with a diameter-to-wall-thickness ratio (D/t) between 15 and 45. The European Pipeline Research Group evaluated whether the existing design equations can be used for very thick-walled pipelines with D/t below 15 that are subject to external pressure and bending, without affecting the level of conservatism underlying the code framework. Based on the adopted assumptions, the limit-state formulation for load-controlled behaviour was found to be increasingly conservative if D/t reduces and the pressure is relatively close to the collapse pressure.

INTRODUCTION

Background

Intecsea reviewed the status of deep-water pipeline technology for the European Pipeline Research Group (EPRG) Design Committee as part of EPRG Project 178/2015 ("Deep water pipelines – Gap analysis"). This study covers a gap analysis and was concluded in 2016. Areas that require further research were identified and subsequently included in EPRG's research road map. An important gap is the absence of a reliable and valid limit-state formulation for local buckling of thick-walled pipe when loaded by a combination of bending, axial force, and pressure. The limit-state formulations for local buckling included in DNVGL-ST-F101 (DNV GL, 2017), which is widely used for the design of subsea pipelines, are stated not to be valid when the diameter-to-wall-thickness ratio (D/t) is less than 15.

Deep-water pipelines installed to date require D/t in the order of 20 for external pressure design. This is the case in maximum water depths in the range of 2,000–2,500 m. When moving to ultra-deep water, the required D/t can be even lower than 15. This asks for technological advancements, which should also be sought in a fundamental review and a potential reformulation of the existing design equations.

In addition to the lack of adequate design equations, manufacturability of line pipe with an extremely thick wall, meaning very low D/t, may be beyond the capabilities of the leading pipe mills. This depends on the selected manufacturing method; this paper considers seamless (SMLS) and longitudinally arc-welded (SAWL) pipe. The design of pipelines with D/t below 15 needs documented information on what can be produced and according to which specification.

Scope

This paper presents the main findings of EPRG Project 202/2017 ("Pipeline design for thick pipe (D/t ratio below 15)") that assesses the validity of the existing design equations for local buckling under external overpressure for thick-walled pipe. This project is a phase of a longer-term research program aimed to understand and overcome the existing technological barriers to the application of tubular products in ultra-deep water and under extreme high-pressure conditions. The following steps were taken:

1. *Review of design, manufacturability, and welding of pipe with low D/t*—Collect best practices on the design aspects related to local buckling, determine what can be achieved by the world's leading pipe mills in terms of line-pipe geometrical and mechanical properties, and determine the practicably achievable high-low (geometrical) misalignments at girth welds for thick-walled pipe.
2. *Numerical assessment of combined-loading local-buckling limit state*—Perform an initial investigation using finite-element analysis (FEA) on the validity of existing design equations for local buckling with external overpressure.
3. *Design recommendations*—Provide preliminary design guidelines and recommendations on research areas in future study phases.

As part of step 1, pipe mills, operators, and installation contractors were consulted by means of questionnaires. Their feedback was interpreted, and relevant findings were used as input for finite-element (FE) modelling that is part of step 2.

Cases

EPRG members—including pipeline operators, line-pipe manufacturers, and installation contractors—were consulted to establish representative cases that require D/t below 15. To capture both SMLS and SAWL pipes, the following three cases are considered: (1) a 6-inch flowline, (2) a 16-inch gathering line, and (3) a 24-inch export pipeline. For these cases, the design water depth is

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KEY WORDS: Pipelines, thick wall, collapse, external pressure, deep water, local buckling, combined loading.