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Effects of impact loads on CRA-Lined pipelines

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ABSTRACT

Third party threats from accidentally dropped objects could cause external impact loading that may potentially affect the integrity and safety of a subsea pipeline system. These incidents may occur during installation, construction and operation phases of the project.

To evaluate the structural integrity of carbon steel (CS) subsea pipelines due to dropped objects events, risk assessment is conducted following the procedure detailed in DNV-RP-F107, which gives a closed-form formula for predicting the impact-energy capacity of the CS pipeline and assumes an acceptance criterion of limiting the dent-depth ratio to 5% of pipe diameter for a no-leakage condition. In the case of CS pipelines mechanically-lined with corrosion resistant alloy (CRA), the applicability of the impact-energy formula and the acceptance criterion is, however, largely unknown considering that CRA-lined pipes involve additional modes of failure in the form of liner separation and its potential for subsequent fatigue failure during operation.

This paper discusses finite element modelling undertaken to evaluate the structural response of a CRA-lined pipeline subjected to external impact loads. Results confirm that liner separation is of minor importance and the use of the established acceptance criterion derived for plain carbon steel pipes can be justified to apply to CRA-lined pipelines.

1. Introduction

As the global energy demand grows with time, the increased exploitation and recovery of offshore natural resources has invariably led to numerous fields where the produced raw gas contains significant levels of compounds (carbon dioxide and hydrogen sulphide) that may make the anticipated flow stream highly corrosive for carbon steel flowlines/pipelines and will require a corrosion mitigation method. As an alternative to chemical corrosion inhibition the pipeline can be protected by materials that are inherently corrosion resistant to the produced fluids, i.e. corrosion resistant alloy (CRA). Line pipes constructed from CRA entirely are expensive and, hence, carbon steel pipes internally clad or lined with a CRA are typically used.

In the case of clad pipes, the CRA material is applied to the inner surface of the carbon steel pipe by means of a metallurgical bond. Lined pipes, on the other hand, are produced by hydrostatically or mechanically expanding a CRA liner onto the inner surface of the carbon steel pipe. The lined pipe joint is supplied with a CRA seal weld on each end for site welding purposes.

Although the CRA-lined pipe provides significant cost savings, it poses additional failure modes in comparison to clad or solid CRA pipes (Focke, 2007). The primary limit state condition for lined pipe is the onset of local buckling, or wrinkling, of the liner as shown in Fig. 1, either due to an impact load or the combination of bending and axial compression load. The wrinkled liner may suffer from early fatigue failure due to cycles of stress concentration from pressure and temperature variations during operational shutdowns. Other potential failure modes include fracture of girth welds; however, since there is no risk of seal-weld separation at this location, this is expected to happen only at higher impact loads. The present study thus focuses on assessing the CRA liner wrinkling due to impact loads and the associated risks.

2. Dropped object risk assessment

The DNV recommended practice for integrity management of submarine pipeline systems, DNV-RP-F116 (2009),[1] notes that the most common pipeline threats may be organised into six threat groups. The threats from accidentally dropped objects resulting in impact loads are defined under the third-party threats group.

Dropped objects causing damage to subsea pipelines and structures

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[1] DNV-RP-F116 has been superseded by DNVGL-RP-F116.

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Notations

3-D	Three-Dimension
CRA	Corrosion Resistant Alloy
CS	Carbon Steel
FE, FEA	Finite Element, Finite Element Analysis
EPRG	European Pipeline Research Group
OD	Outside Diameter
SIMOPs	Simultaneous Operations

Fig. 1. Liner separation and wrinkles observed after bending Test (Focke, 2007).

may occur during installation, construction and/or operation activities. Simultaneous operations (SIMOPs) of drilling and production undertaken during infill drilling and well intervention campaigns throughout the life of the project are known to pose high likelihood for dropped objects causing damage to the subsea production systems (DORIS, 2011). The consequence of this damage to CRA-lined subsea flowlines is potential for loss of containment, i.e. an environmental risk. Such a loss can lead to safety risk to the rig personnel due to significant inventories in the subsea flowlines. There is also asset risk from the seawater ingress resulting in loss of flowline due to severe corrosion.

To assess the impact risk on the pipeline, probability risk assessments are conducted following the standard methodology described in the recommended practice, DNV-RP-F107 (2010). The probability that an impact results in damage is established based on the impact energy estimate and the impact energy capacity for the installed subsea equipment.

2.1. Impact energy capacities

Impact damage is based on an energy balance approach where the available kinetic energy from an impacting object is compared to the energy required to produce a dent. The dent size, expressed as a percentage of the overall pipeline diameter, is an indication as to the likelihood of a leak or rupture.

DNV-RP-F107 (2010) [2] provides a relation for determining the impact energy required to dent the pipeline due to dropped objects. The closed-form equation shown below, assumes a rigid knife-edge, impacting perpendicular to the axis of the pipeline.

$$E = 16\cdot\sqrt{\frac{2\cdot\pi}{9}}\cdot m_p\cdot\sqrt{\frac{D}{t}}\cdot D\cdot\left(\frac{\delta}{D}\right)^{\frac{3}{2}}$$

$$m_p = \frac{1}{4}\cdot\sigma_y\cdot t^2 \tag{1}$$

where E is the impact energy, δ is the dent depth, t is the pipe wall thickness, σy is the material yield stress, m_p is the plastic moment capacity of the pipe wall and D is the pipe outer diameter.

It is noted the empirical formulations in the recommended practice for impact assessments are based on plain carbon steel, which is a significant idealisation for CRA lined pipelines. An additional risk could result due to local deformations imposed by impact loading in the vicinity of inherent weld defects at girth welds. This form of potential failure mode is not considered here.

2.2. Allowable dent depth

Section 4.2 in DNV-RP-F107 (2010) describes the damage classifications used to define severity of dent depth. The acceptance criterion is based on limiting the damage in the pipe in terms of the ratio of dent depth to pipe diameter to a maximum of 5% for damage category 'D1' as specified in DNV-RP-F107 (2010). The dent depth in the steel pipe wall of up to 5% of the diameter will not normally have any immediate influence on the operation of the lines, including pigging.

Whilst the results from the dropped object risk assessment may show that the risk of a dropped object exceeding the pipeline resistance is low, there is still the requirement to justify the use of the following assumptions for CRA-lined pipeline:

- In terms of impact-energy capacity, an equivalent plain carbon steel pipe with the total thickness of the backing steel pipe and the CRA liner can represent the CRA-lined pipe and, hence, Equation [1] above for predicting impact–energy capacity may be used.
- The 5% OD dent-depth limit ensures no damage to the CRA liner and no leakage in the backing steel pipe including the effects of a gouge.
- The 5% OD dent-depth limit also ensures that the allowable fatigue damage at the dent location is the same as that for the undented pipe.

During the design phase of a recently completed subsea project a case study of the impact resistance of CRA-lined flowline was conducted to justify the above assumptions. The flowline was designed in accordance with DNV-OS-F101 (2010) [3] for its general mechanical requirement and SAFEBUCK guideline (2008) for its lateral buckling mitigation. The case study utilised 3-D nonlinear, dynamic finite element analysis (FEA) to investigate the impact resistance of a 14-inch flowline with the following parameters that resulted from the design:

- Seamless pipe with 14.3 mm wall thickness made of DNV-Grade 450 carbon steel
- 3 mm thick internal liner made of AISI 316 stainless steel
- Design pressure equal to 73% of steel pipe burst pressure
- Allowable fatigue damage over the design life of 4% which accounts for the design fatigue factor in DNV-OS-F101 (2010), proportion of fatigue during installation and operation, and a project-specified knockdown factor for fatigue in CRA-lined pipe
- Deepest end of the flowline in 230 m water depth

The design of the flowline includes 5LPP insulation coating that was conservatively neglected in the present analysis of the impact-energy capacity of the CRA-lined pipe itself. Polymer coating absorbs a proportion of the impact energy, and DNV-RP-F107 (2010) provides an estimate of the energy-absorption capacity of different thicknesses of polymer coating.

3. Impact loads from dropped objects

Dropped objects possess a certain energy a portion of which is transferred to the subsea asset upon impact, resulting in varying degrees of damage depending on the properties of both object and impacted assets.

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[2] DNV-RP-F107 has been superseded by DNVGL-RP-F107.

[3] DNV-OS-F101 has been superseded by DNVGL-ST-F101.