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Assessment of dropped object risk on corroded subsea pipeline

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ABSTRACT

The rapid increase in offshore to onshore hydrocarbon transportation has prompted the expansion of subsea pipeline networks to meet energy demands. In offshore platform, unexpected accidents such as fractional dents or fractures may occur in proximity of subsea pipelines due to transverse loading or external forces during operation and installation. Partial damage may cause leaks and oil spills, and in serious cases, the sequence may lead to fire and severe explosions. Meticulous safety measures should consider safety issues and mitigate different extent of risk to the life, environment and assets. To avoid these undesirable events, this study presents a probabilistic and numerical modelling analysis of accidental scenarios to verify the safety of subsea pipelines under different conditions. An impact analysis of transverse loading on a subsea pipeline is performed using scenario sampling and finite element analysis to assess safety measures and mitigate damage by evaluating the effects of impacts in different possible accidental scenarios.

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1. Introduction

The world's energy consumption has increased over the past few decades, and it is estimated that the energy demand will continue to rise. This increased demand and the limited onshore reserves have led to increased offshore exploration and the rapid expansion of offshore structures and subsea transmission systems. During the installation and operation of offshore platforms, transverse loading from a heavy object dropped into the seawater could cause significant impact damage to the subsea pipeline networks and risers. In severe cases, the fracture of subsea pipelines and risers might lead to containment failure and leak of hydrocarbon into the seawater. The oil spill incident of the Deepwater Horizon offshore facility shown in Fig. 1 is considered to be one of the largest containment failure in the petroleum industry; 4.9 million barrels of crude oil leaked onto the ocean floor, approximately 42 mile off the coast of Louisiana. Such accidental containment failure could also result from pipeline fracture due to impact loading and could be responsible for partial failure of the production system and adverse effects on the environment depending on the volume of hydrocarbon leaked. The most comprehensive database of offshore pipeline failure is available in the report of the UK Health and Safety Executive PARLOC 2001 (HSE, 2003) and the PRC, International American Gas Association (IAGA) (1999, 2000). The data indicate that about 47% of pipeline failures were caused from external impact, as shown in Fig. 1.

To mitigate such catastrophes, the offshore industries are evolving towards a quantitative proactive methodology. The industries are adopting a formalized specialist method approved by DNV GL by following the design criteria of formal safety assessment proposed by the International Maritime Organization (IMO, 2002). The offshore industries are utilising quantitative risk assessment (QRA) in formal safety assessments to reduce risk and improve safety issues in offshore structures. Although many studies have included QRA and impact analysis, the practical implementation of QRA for the unburied submarine pipeline layouts and transmission systems close to offshore platforms still endured by many limitations.

In recent years, several studies have proposed relevant analysis method in the field of offshore risk assessment (Bai and Bai, 2005, 2014; Vinnem, 2007). Bai and Bai (2014) suggested the probability and consequences of the failure of subsea pipelines from different types of impact and investigated the prediction of risk and acceptance criteria to establish an optimal plan for inspection. After the Piper Alpha disaster in 1988, Pate-Cornell (1993)

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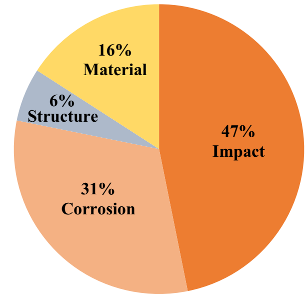

Fig. 1. Explosion of the Deepwater Horizon as a result of containment failure (http://www.eoearth.org/) (left) and Antecedents of subsea pipeline failure incidence (right).

introduced a probabilistic risk analysis framework to identify a wide span of possible risk optimisation and management strategies.

This study implements a QRA model of application proceeding DNV•GL (DNV-RP-F107, 2010) by conducting numerical simulations with finite element analysis based on statistical sampling and probabilistic assessment of transverse accidental loading on submarine offshore transmission lines. In one side, a statistical sampling technique is used for the probabilistic estimation of event occurrence. On the other, numerical simulation technique is used to address structural integrity in case of impact scenario. The computational and statistical analyses involve the impact consequences and likelihood to predict the probability of accidents and the extent of damage. This study discusses the consequences of an impact failure of a subsea pipeline and assesses the potential risk analysis process to life, assets and the environment from an offshore hydrocarbon transmission facility.

Researchers investigating the dynamic responses of subsea pipeline structures and have proposed several experimental and numerical approaches for analysing the consequences of an impact. Wierzbicki and Suh (1988) performed a theoretical analysis of large plastic deformations in tubes under lateral indentation, bending moment and axial force. Roy et al. (1997) presented numerical simulations of full-scale corroded pipes under combined loading. Leu (1999) extended the study by conducting a finite element simulation of the lateral compression between rigid plates. Brooker (2004) performed a numerical simulation of quasistatic lateral indentation with continuous support at the base and full restraint at each end. The perception of failure model and the dissipation pattern of the impact energy contributed to the design of more reliable structures and the evaluation of existing designs. Abosbaia et al. (2005) examined the energy absorption capability of laterally compressed quasistatic composite tubes. Alghamdi (2001) investigated collapsible impact energy absorbers and a model of deformation for tubes of different shapes. Arabzadeh and Zeinoddini (2011) investigated the dynamic response of pressurised submerged pipelines under transverse loading conditions.

This study proposes statistical and numerical methods for analysing the impact of a dropped object on a subsea pipeline to measure the accidental effects and to mitigate the risk of different possible accident scenarios. Accidents involving impact loading on globally distributed offshore platforms over the transmission system may involve discrete scenarios and different specifications depending on the geographic location. The impracticality of considering every possible accident scenario in a numerical analysis inspired a statistical sampling approach in which a set of representative scenarios for various possible situations are selected for a specific structure (Ye, 1998). The proposed method is also applicable for the assessment of other platforms according to specified parameters and in consideration of an extended range of parameters or different situations. This study considers such conditions to predict the damage consequences of randomly selected sampling scenarios using a nonlinear finite element method (FEM). The results of the simulation are used to calculate indentation, material absorbed energy and fracture properties. In addition, since the corrosion and shape of the striking object influence the fracture properties these must be considered in the computational evaluation and analysis of the results. In conclusion, the consequence and likelihood exceedance curve are presented to define acceptance criteria for indentation and absorbed energy that can be considered in accidental limit state design.

During the installation and operation of offshore platforms, several hypothetical accidental situations consider influential parameters such as the depth of the water, the weight and shape of the object and the angle of descent to measure the drag and terminal velocity. Even though objects lifted onto an offshore platform may have the shape of a box or sphere, the wind, waves, current or angle of descent may change the object's shape during contact. The object may thus have different dimensions at the time of impact with the pipe, which would result in a different magnitude of damage. The angle of action is considered to be a function of mass and external forces. Hydrostatic pressure and internal pressure must be considered for proper analysis of the impact's effects. The pipeline's material properties, such as its mass density, yield stress, Poisson's ratio and Young's modulus, and physical dimensions, such as the diameter and wall thickness, were defined in previous studies on the same material (Ilman and Kusmono, 2014).

The results of the present simulation may vary from other results because the designer's modelling simplification and assumptions differ in many respects. For accurate and precise calculation, many researchers have developed different approximations in FEM and have considered different parameters or approaches; however, each method has specific applications. This paper focuses on the methods of safety assessment, and a numerical modelling technique is developed for simplicity and a short computational time.

2. Working principle

QRA is a probabilistic and numerical process of measuring risk using frequency and consequence analysis. Its primary steps are hazard identification and consequence analysis through numerical simulation. Fig. 2(a) shows a systematic procedure of QRA and risk control based on the formal safety assessment probability diagram of the International Maritime Organisation (IMO, 2002).

The main objective of the proposed method is to determine impact frequency and consequences through numerical simulation with FEM to assess whether the risk are controlled within acceptance or not. In QRA studies to assess risk control, measurement of the consequences is a fundamental quantity. The study considers quantitative measurement of impact frequency and consequences using the working principle shown in Fig. 2 (b) below.

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