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Review

Pipelines, risers and umbilicals failures: A literature review

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ABSTRACT

The exploratory frontier of offshore oil and gas industry comes into deeper waters, with the 3000 m water depth barrier hurdled in the US Gulf of Mexico in 2003. At these water depths, the extremely high external pressures, low temperatures, long distance tie-backs and high environmental loads due to waves, currents, and wind combined brings the employed equipment to its operational limit. This paper presents a literature review on failure events experienced by the industry concerning pipelines, risers, and umbilical cables, describing their causes, consequences, and severity. From the several failure modes reported up to now, it is possible to select the ones that are more frequent and deserves attention from academia and industry. Concerning pipelines, the main failure modes reported are due to mechanical damage, corrosion, construction defect, natural hazards and fatigue. Additionally, a vast review of published researches concerning the pipeline-seabed interaction is presented. With regard to floating risers, approximately 85% of them are of flexible type. Although flexible risers may fail in different ways, collapse due to external pressure is reported as the most frequent failure mode. For umbilical cables, the major failure modes are found to occur under tension or compression, torsion, fatigue, wear and sheaving.

1. Introduction

Oil and gas exploration and production in deepwater is associated with the use of highly sophisticated equipment and increasing innovative technology. However, the failure of this equipment can cause serious consequences, including material loss and environmental pollution. Critical accidents can even cause the loss of human lives. Based on a literature review, this paper aims to identify past typical failures experienced in the industry concerning pipelines, risers, and umbilicals, detailing the causes, consequences, and severity of these failures.

Pipelines are the safest method to export liquid and gaseous petroleum products or chemicals (Roche, 2007). However, like any engineering structure, pipelines do occasionally fail. The main failure modes experienced by pipelines during production are identified as mechanical damage (impact or accidental damage), external and/or internal corrosion, construction defect, material or mechanical failure, natural hazards and fatigue.

Risers are oil and gas transfer lines of much importance to offshore oil and gas production systems. They comprise the dynamic segment of an exportation pipeline or a production flowline connecting seabed to the production unit at sea level. They are affected by mechanical stress, environmental issues and individual conditions resulting from the geographic location where the production unit has been installed. Risers can be classified as flexible or rigid. For flexible risers, the major failures experienced are due to fatigue, corrosion, torsion, burst, collapse and overbending. For rigid risers, the most common external threats are impacts, internal and/or external corrosion, overstress, fatigue, structural wear, structural instability, material degradation and fire/explosion (in surface segments).

Umbilical cables are responsible to control subsea equipment like Xmas trees, manifolds, pumps, separators, etc. Bryant (1990) identifies the failure modes of umbilical cables as tension or compression, torsion, fatigue, wear and sheaving. These failures modes are discussed with particular focus on sheaving, which is associated with the use of static sheaves, such as curved plates during umbilical installation.

This work is motivated by the need of extensively address studies about the safety of offshore operations in deepwater and ultra-deepwater scenarios, like pre-salt fields in the Brazilian Santos Basin. The compiled information can be used as a guide to initiate studies on structural integrity. The possibility of contributing to the establishment of a national program of offshore safety in Brazil, with emphasis on technological advances that aim the prevention of accidents, is also a motivation for this research.

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2. Pipeline failures

According to the US Pipeline & Hazardous Materials Safety Administration (PHMSA, 2014), there were a few more than three hundred offshore pipeline incidents in the U.S. in the past ten years, seventy one involving hydrocarbon releases (Aljaroudi et al., 2015).

Pipeline failures are usually related to a breakdown in the system, for example, the loss of corrosion protection, meaning a combination of ageing coating, aggressive environment, and rapid corrosion growth that may lead to a failure. This type of failure is not simply a corrosion failure, but a corrosion control system failure. Similar observations can be drawn for failures due to external interference, stress corrosion cracking, etc. (Cosham and Hopkins, 2002).

Based on four different databases that include only accidents that led to loss of containment, De Stefani and Carr (2010) pointed out the following as the most probable failure modes in pipelines: mechanical damage (which includes impact and any external damage), external or internal corrosion, construction defect, mechanical or material failure, and natural hazards. Stadie-Frohbös and Lampe (2013) also studied offshore pipeline failures. Based on existing codes as DNV-RP-F116 (2009) and historical records considering 22 offshore pipelines, the authors concluded that beside the failure modes mentioned above, erosion, structural threats (fatigue and static overloads, particularly at free spans) and unpredicted operation are also possible failure modes.

Based on pipeline and riser loss of containment (PARLOC, 2003) and data from PHMSA (2014), Stadie-Frohbös and Lampe (2013) concluded that impact is the major cause of failures in offshore pipelines in operation at North Sea, representing 56% of the total failures between 1971 and 2000. In the US, comparing all failures reported between 1995 and 2011, 31% are caused by corrosion. These numbers and those of other failure causes are summarized in Fig. 1.

The difference between the two scenarios (US and North Sea) may be explained by geographic reasons. At the shallow waters of North Sea, the impact of a dropped object is most probably than at US deepwaters, since the current action can deviate the object from the undesirable target. On the other hand, hurricanes are frequent at US, increasing the failures by natural hazards at those fields. Anyway, corrosion is always an issue of concern for both scenarios.

Review and analysis of historical causes of pipeline failures worldwide indicate that corrosion, especially internal corrosion, is the most widely reported cause of failure of offshore pipelines, followed by maritime activities (anchor or trawling damage and vessel collisions), and natural forces like storms and mudslides (Hokstad et al., 2010).

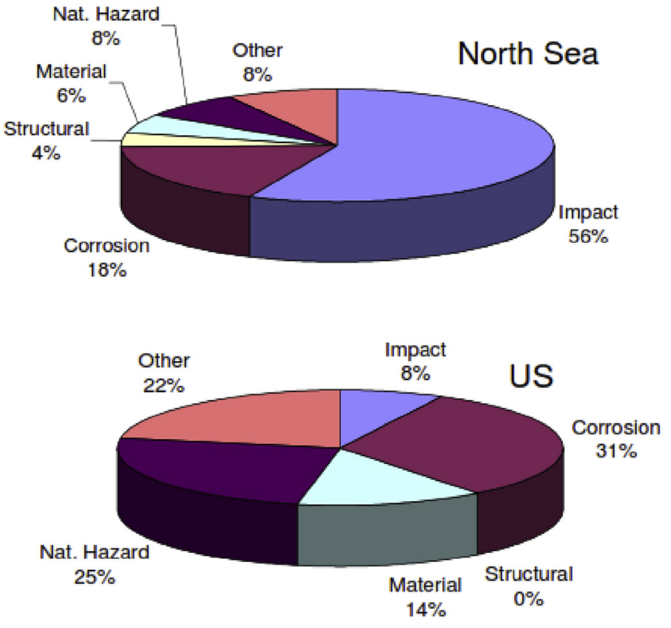

Fig. 1. Offshore pipeline failures (Stadie-Frohbös and Lampe, 2013).

Corrosion reduces the pipeline's strength and capacity to endure operating pressure leading to two possible failure events: leakage or burst. Leakage failure occurs when corrosion fully penetrates the pipeline wall thickness, while burst failure occurs when operating pressure exceeds the maximum allowable pressure at a defect point (Aljaroudi et al., 2015). All internal and external corrosion occurrences affecting pipelines used in the oil & gas industry are of electrochemical nature, i.e. they need the presence of water in contact with steel and oxidizing species dissolved in water for feeding corrosion cells (Roche, 2007). At ultra-deepwater scenarios, thickness reduction can cause collapse under external pressure rather than burst under internal pressure.

Cathode protection (CP) and coatings are used to protect offshore transportation pipelines. According to Roche (2004), as long as coatings remain bonded to steel and cathode protection is correctly applied, monitored and maintained, no external corrosion risk exists. However, the same author, in another paper published three years later, stated that not even the risk of corrosion under unbonded coating is a concern to offshore pipelines integrity. This is probably due to the high conductivity and homogeneity of seawater, which makes easier the access of CP current underneath electrical shields (Roche, 2007).

According to Roche (2007), most of the leaks due to internal corrosion have been explained by microbiologically Induced corrosion (MIC) or by ingress of CO_2 traces combined with H_2S. The first parameter determining corrosion risks is the presence of water in contact with steel surfaces. This contact is obvious for injection water lines. In the case of oil pipelines, water may be in contact with steel at the bottom of the pipe, settled by gravity, and on the flow pattern, depending on the water content. For wet gas pipelines, water is separate also at the pipeline bottom line, but in some cases condensation may occur if the gas is hot at the top line when cooling from outside is significant enough. Several types of corrosion may occur at locations where water is in contact with steel as long as oxidizing species are present. The most frequent species are CO_2, light organic acids, H_2S and O_2. Most often, corrosion pattern is in the form of pits, craters or more uniform wall thinning.

In India offshore facilities, premature leaks in subsea water injection pipelines due to rupture were observed. Analysis of different operating parameters and water quality indicated failure due to microbial induced internal corrosion. According to Samant and Singh (1998), this kind of corrosion was due to low flow velocities, insoluble corrosion products suspended, iron oxide, iron sulfide, and bacteria present in the water accumulated at the bottom of the pipe. Moreover, non-pigging of the pipeline might have allowed bacteria to multiply rapidly and develop colonies and biofilm, which provides a hiding sites for bacteria and shielded them from effective treatment by bactericides. Due to lack of frequent pigging and an effective microbiocidal treatment procedure, the uncontrolled growth of bacteria occurred. Consequently, microbial activities dominated and led to an acidic environment that ultimately caused internal severe localized corrosion (Samant and Singh, 1998).

Another pipeline failure case was reported by Rose (1999) and was attributed to girth weld problems. At Point Pedernales field, California, a complete and sudden failure of a subsea pipeline caused the release of 163 barrels of crude oil into the Pacific Ocean. A crack occurred at a girth weld between pipe body and the flange bell. After investigation and analysis of the failure, it was concluded that the crack initiated at the heat-affected zone leading to a complete separation of the flange bell. The examination revealed that the heat-affected zone was brittle, possibly due to a lack of preheating prior to welding. Therefore, numerous microcracks have developed, one of which being the failure initiation site (Rose, 1999).

Amend (2010) attributed to welds the responsibility for more than 6% of significant pipeline failures. The author stated that pipeline girth welds are unlikely to fail unless subjected to axial strains that far exceed