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Enhancing offshore process safety by selecting fatigue critical piping locations for inspection using Fuzzy-AHP based approach

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ABSTRACT

Topside piping is the single largest source of the hydrocarbon releases (HCRs) on the offshore oil and gas (OOG) platforms in the North Sea region. Consequently, if the leaked hydrocarbons from the process pipework are ignited, it may lead to a catastrophic event, thereby causing significant economic losses, environmental damage, and posing serious threat to the safety of the onboard personnel. In order to avert such a fateful event and to enhance process safety, it is vital to maintain the technical integrity of the topside piping. In regard to this, risk based inspection (RBI) plays a vital role, as the inspection locations and frequency are decided based on the risk of potential failure. However, international standards such as API 570, API 581 and DNV RP-G101 provide limited guidance in regard to inspection of the fatigue degradation of the offshore topside piping. Due to the aforementioned, selection of the fatigue critical piping locations for inspection, is currently done either on the ad-hoc basis or using the three staged Risk Assessment Process (RAP) mentioned in the Energy Institute (EI) guidelines. Nevertheless, it has been revealed that the methodology for stage 1 of the RAP is laborious and time consuming. Thus, to reduce the toil of the practicing inspection engineer and with the aim of mitigating the dearth of RBI methodologies for topside piping fatigue, this manuscript proposes a Fuzzy-Analytical Hierarchy Process (FAHP) centered approach for selecting the fatigue critical piping locations for inspection and repair. The usability of the proposed approach is demonstrated by an illustrative case study.

1. Introduction

1.1. *Background*

Throughout the offshore oil and gas (OOG) industry, considerably effort is being laid on enhancing the process safety, in order to prevent hydrocarbon releases (HCRs) from the offshore production facilities (OGP, 2011). The reason for the aforementioned is that, if the leaked hydrocarbons are ignited, it may lead to a catastrophic event, thereby causing significant economic losses, environmental damage; and posing serious threat to the safety of the onboard personnel. During the period between 1996 and 2011, an average of 23.3 hydrocarbon leaks above 0.1 kg/s were registered on the offshore platforms in the Norwegian Continental Shelf (NCS) (Bergh et al., 2014; PSA, 2012). Statistics indicate that the single largest contributor of the HCRs on the OOG platforms in the North Sea region is the topside piping (as pipework contributed to 56% of failures on OOG platforms in the UK sector of the North Sea), followed by valves, flanges and other pressure equipments (HSE RR672,

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2008). Furthermore, cracking of the Small Bore Connections (SBCs) due to the Vibration Induced Fatigue (VIF) is the most common cause of the HCRs from the process pipework (HSE RR672, 2008).

Even though piping is the most common source of HCRs on the offshore platforms, it is unfortunate that due to the tumbling oil prices certain companies have deferred the inspection and maintenance activities for the topside piping (Vicente, 2014). The reason for such an aberration is that the asset integrity management (AIM) program of these companies predominantly focuses on other equipment such as pressure vessels, even though vessels contribute to 18% of failures on the OOG platforms (HSE RR672, 2008; Vicente, 2014). Hence, these companies are ignoring the risk posed by the piping failure, which eventually leads to the release of the hydrocarbons from the offshore pipework.

In order to prevent the HCRs from the topside piping and to enhance the process safety, it is vital to assure the integrity of the pipework, such that the topside piping is structurally sound, and performs the designed function (OGP, 2008). This is achieved by effective design, high quality fabrication, good operating practices, and an efficient risk based inspection and maintenance plans (Antaki, 2003). However, despite the efficient design, topside piping encounters vibrational issues during its service life, which eventually causes failure and HCRs. This is primarily due to the changes in operational conditions, varying loads, varying flow phase and wall thinning of piping during its operational life (Antaki, 2003). Thus, in order to prevent the HCRs from the offshore piping there is a need of selecting fatigue critical piping locations for the inspection and repair activity.

1.2. *Industrial challenges and constraints*

Framing an in-service inspection strategy for the process pipework on the OOG platforms is considered one of the main challenging areas. This is primarily due to the large amounts of topside piping (with varied diameters) in the constrictive space. Some of the additional industrial challenges in regards to the inspection planning of the offshore topside piping undergoing fatigue degradation are:

(a). In the UK and the Norwegian offshore industry, carbon steel piping has been extensively replaced by the duplex stainless steel piping during the past 40 years (Jungbauer et al., 1995). The reason for such widespread modification in the piping material is due to properties such as better corrosion resistance, high strength (meaning thin walled piping) and the light weight of duplex stainless steel (Gunn, 1997). Conversely, thin walled duplex piping poses severe vibrational problems, which eventually causes fatigue failure of the topside piping (Jungbauer et al., 1995). Thus, with the onset of duplex stainless steel piping, the number of fatigue critical location on offshore piping has increased significantly; consequently, increasing the likelihood of the HCRs on the OOG platforms. Additionally, it is cumbersome to inspect the large number of the fatigue critical piping locations to enhance the process safety on the OOG platforms.

(b). Uncertainty in the information related to the degraded state of the system serves as a hindrance for framing optimal inspection/maintenance plans (Ling and Mahadevan, 2012). In the aerospace industry, this uncertainty is mitigated to some degree by the online data available from the Structural Health Monitoring (SHM) devices (Ling and Mahadevan, 2012). Comparatively, such a practice is less commonly used in the Norwegian offshore industry for the fatigue degradation monitoring of the offshore topside pipework. Consequently, for framing an optimum inspection strategy for fatigue degradation in offshore pipework, companies mainly rely on sources such as, the expert opinion regarding the technical reality of the system, the Non Destructive Testing (NDT) data obtained from past inspections and the guidelines in the international standards. Generally, the former two sources are infused with significant level of uncertainty, hence, the inspection recommendations based on the aforementioned may be incorrect unless certain measures are taken to handle the uncertainty in them. Likewise, the number of international standards providing guidelines for selecting fatigue critical piping locations for inspection is minimal. According to authors' best knowledge, the only standard providing the guidelines in the aforementioned direction is the Energy Institute (EI) guidelines for avoidance of VIF in the process pipework (EI Guidelines, 2007).

(c). Even though the EI guidelines provide qualitative assessment for identifying fatigue critical piping system, still at present, the selection of the fatigue critical inspection locations on offshore pipework is mainly done on the ad-hoc basis. This is a risky practice, as the selection of inspection location done on the ad-hoc basis does not account for the risk of potential failure. Such a practice increases the likelihood of the HCRs from the process pipework, thereby reducing the offshore process safety.

In light of the above discussion, it is stated that currently the EI guidelines provide a three-staged, Risk Assessment Process (RAP) to identify fatigue critical inspection locations on the topside piping (EI Guidelines, 2007). The EI guidelines also provide various assessment techniques (such as quantitative, visual, etc.); to be used during stages 2 and 3 of the RAP. The aforementioned assessment techniques screens the mainline piping and SBCs on the basis of likelihood of failure (LOF) due to the VIF (EI Guidelines, 2007). Furthermore, the guidelines provide a detailed qualitative assessment technique, which should be employed during stage 1 of the RAP for the identification of applicable excitation mechanisms to be considered in stage 2. However, in regard to system identification during stage 1 of the RAP, the guideline recommends on performing the qualitative assessment for each of the system (considered for analysis) individually (EI Guidelines, 2007).

It has been revealed that performing qualitative assessment of large number of systems during stage 1 of the RAP is a laborious and time consuming task. The aforementioned has been verified over the several discussions that has been carried out with the practicing inspection engineers. The majority of the inspection engineers, whom the authors consulted, expressed a need for a simpler screening methodology, which shall be employed during stage 1 of the RAP for identification of fatigue critical systems. Consequently, the authors proposed an Analytical Hierarchy Process (AHP) based methodology, which may be employed during stage 1 of the RAP (Keprate and Ratnayake, 2015a). The aim of the AHP based approach is to identify fatigue critical piping system and the applicable excitation mechanism during stage 1 of the RAP. Nevertheless, the aforementioned approach is inflicted with the following constraints: