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Determination of design accidental fire load for offshore installations based on quantitative risk assessment with treatment of parametric uncertainty

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A B S T R A C T

This study investigated the critical issues for determining the design accidental load (DAL) fire procedure based on quantitative risk assessment (QRA) for offshore installations. Considerable attention was paid to parametric uncertainty in choosing the numerical values used for the frequency and consequence analysis. In particular, selecting the initial leak size was one of the most critical aspects, and inconsistent approaches for selecting this value resulted in different risks for identical systems. Frequency analysis of past investigations also overlooked the inaccuracy and unsuitability of statistical data. Accordingly, the estimated risks were significantly uncertain, and the lack of information about the results increased the risk of making the wrong decision. In this study, the Latin hypercube sampling (LHS) technique was used to treat parametric uncertainty in QRA. Different fire exceedance curves and DAL fires were demonstrated by selecting different sets of representative values. The distribution and confidence interval of the DAL fires showed a wide distribution with varying uncertain and critical parameters. Therefore, this procedure provided quantitative information on inherent uncertainty, and such additional information regarding DAL fires can lead to better decision making.

1. Introduction

Offshore installations are operated in extreme marine environments and are intrinsically threatened by various hazards that cause harmful consequences such as injury to or death of operators, damage to assets, physical and biological facility degradation, interruption of oil and gas production, and business disruption (Spouge, 1999). The main hazards include ship collisions, dropped objects, fires, and explosions (DNV, 2010), with the last two being the most critical of these hazards. Specifically, the topside of offshore platforms, which treats combustible oil and gas, is consistently exposed to hydrocarbon fires and explosions with the potential for disastrous consequences.

To reduce the risk of such disasters, the industry has made an effort to provide a combination of prevention, detection, control and mitigation measures. The performance standards for these measures should be consolidated at the concept design stage, when design and operating philosophies are established, and the systems should be designed to meet these philosophies as well as normal engineering acceptance criteria. In this situation, the concept of "design accidental load" (DAL) has been introduced to ensure the safety of offshore installations (HSE, 2000). The purpose of identifying and assessing the DAL is to verify that accidents do not cause risks that exceed the defined criteria for the design of the structures (ABS, 2013; DNV, 2010).

Quantitative risk assessment (QRA) has also been employed as a rational and rigorous method for risk estimation. QRA uses systematic analysis to quantify risks, which are expressed as a combination of frequency and consequences, and to provide input to a decision-making process. Consequently, QRA has made great advances in recent decades thanks to plentiful theoretical and experimental investigations.

HSE (2000) presented the relationship between engineering acceptance criteria and QRA. QRA determines the realistic and practical accidental loads for specific offshore installations. The systems that are designed in accordance with normal engineering acceptance criteria may be redesigned to resist the DAL derived from QRA. These predictions may prevent over-conservative or

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Abbreviations

ABS	American Bureau of Shipping
API	American Petroleum Institute
A_L	Leak area (m^2)
A_B	Blowdown valve area (m^2)
CFD	Computational fluid dynamics
C_D	Discharge coefficient
γ	Ratio of specific heat
DAL	Design accidental load
DNV	Det Norske Veritas
EF	Error factor
ESD	Emergency shutdown
ETA	Event tree analysis
F	Leak frequency (per year)
FABIG	Fire and Blast Information Group
HP	High pressure
HSE	Health and safety executive
λ	Failure rate (per 10^6 h)
μ	Mean
LHS	Latin hypercube sampling
LP	Low pressure
M	Molecular weight of gas
m_0	Initial inventory mass (kg)
m_B	Mass remaining when blowdown begins (kg)
OGP	The International Association of Oil & Gas Producers
OREDA	Offshore Reliability Data Handbook
P	Conditional probability
PFD	Probability of failure on demand
PFP	Passive fire protection
P_0	Initial inventory pressure (Pa)
P_B	Pressure when blowdown begins (Pa)
P_a	Ambient pressure (Pa)
QRA	Quantitative risk assessment
Q_0	Initial release rate (kg/s)
Q_L	Release rate through leak when blowdown begins (kg/s)
Q_T	Total release rate through leak and blowdown valve when blowdown begins (kg/s)
R	Universal gas constant (8.314 J/mol K)
σ	Standard deviation
T	Test interval (hours)
T_0	Initial inventory temperature
t_I	Time isolation starts (seconds)
t_B	Time blowdown starts (seconds)
$X_{0.05}$	Lower confidence limit
$X_{0.95}$	Upper confidence limit

Subscripts

0.05	5^{th} percentile
0.95	95^{th} percentile
avg	Average
BD	Blowdown failure
ESD	Isolation failure
FD	Fire detection failure
i	Initial event
IG	Ignition

inadequate design (FABIG, 2005).

FABIG (2010) proposed an approach for determining the DAL fire based on QRA for further structural response analysis. This procedure is divided into two sections. Section 1 describes the approach for determining the DAL fire based on QRA. The first step of determining fire load is performing the initial fire risk assessment to assign risk rankings to potential cases by combining leak frequency, ignition probability and segment inventories. Representative cases with the highest potential risk are selected for further detailed frequency and consequence analysis. QRA is conducted to quantitatively calculate the heat loads and probabilities for each fire scenario. The results are then used to establish a fire exceedance plot. The DAL fire is selected based on the acceptance criteria from the cumulative exceedance plot.

The main output from Section 1 is used as input for Section 2. The DAL fire is applied to analyze the structural response to obtain the temperature and strain response. If the result is not acceptable, mitigation measures such as ESD, blowdown, and PFP are improved and installed. These procedures can give optimal design solutions for improving safety and reducing cost.

Although QRA has made substantial advances in recent decades, most types of QRA have overlooked inherent uncertainty. The uncertainty reduces the confidence in the result and increases the likelihood of making the wrong decisions. Aven and Zio (2011) have discussed issues to representing and treating uncertainty in risk assessments to support risk-informed decision making.

Various types of uncertainty in risk assessments have been well recognized, and many researchers have introduced various approaches for representing and quantifying uncertainty (Abrahamsson, 2002; Apostolakis, 1990; Berger, 1994; Chang et al., 2015; Ferson and Ginzburg, 1996; Freeman, 2012, 2013; Helton and Davis, 2003; Thompson et al., 1992; Zadeh, 1983).

Offshore hydrocarbon fire accidents are typically high-consequence and low-frequency disasters. Zio and Aven (2013) emphasized that this type of accident is typically accompanied by uncertainty from a scarcity of empirical and statistical information data compared with the occurrence of offshore hydrocarbon fire accidents. Therefore, this uncertainty in QRA for new systems and/or historically rare events is significant due to the existence of limited information and should be suitably addressed. Nevertheless, few investigations have thoroughly examined the treatment of uncertainty for offshore fire risks. HSE (2006) defined several sources of uncertainty in QRA for hydrocarbon fire hazards. Conservative assumptions were applied to addressing uncertainty in the consequence and frequency estimation.

As described above, QRA is used to calculate the DAL fire that is applied in the structural response analysis, and the required level of PFP coverage is determined depending on whether the structure can resist the DAL fire. However, QRA is always subject to various levels of uncertainty, and the DAL fire may be very sensitive to the results of QRA, which can lead to overly conservative or poor safety design solutions in decision making. Therefore, uncertainty should be treated appropriately, and the QRA results should provide additional information on uncertainty for improved decision making.

This study presents the main sources of uncertainty for determining the fire load in Section 1 of the FABIG Technical Note 11. This investigation is performed to identify the effects of uncertainty on the results of fire risk assessment. A procedure is proposed to quantitatively estimate the uncertainty and improve the credibility of the results. A case study is also performed to determine the DAL fire considering uncertainty.