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# Fire risk analysis procedure based on temperature approximation for determination of failed area of offshore structure: Living quarters on semi-drilling rig

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ABSTRACT

Fire risk analysis (FRA), one of the dedicated safety studies in offshore risk assessment, aims at determining the potential fire scenarios that threaten the offshore plants and its associated facilities. In the detailed design stage, there is a routine FRA procedure that is conducted to probabilistically determine the safety of the topside structure. This procedure, however, lacks a direct probabilistic risk analysis for determination of the design accidental load (DAL) or of the necessary insulated protection applied to the critical targets on offshore plants. This paper conceptually proposes a quantitative-probabilistic FRA procedure for calculating the design temperature distribution and probable failed areas of critical targets. The proposed procedure considers a full combination of blowout scenarios that can possibly take place on a semi-submersible drilling rig. In scenario identification, the probability distributions of random variables related to fire events are taken into consideration. In consequence analysis, a CFD-based fire simulation (KFX, 2010) in conjunction with a heat transfer analysis (FAHTS, 2010) is carried out to calculate the temperature distribution at the wall surface of living quarters (LQ). In response to the heavy computational CFD simulation, this paper also introduces an approximation method to reduce the time cost of analysis, which depends on the number of input scenarios. Lastly, in risk evaluation, the failed area of LQ is predicted using 2 different risk analysis methods: cumulative failure frequency (CFF) and temperature exceedance curve (TEC).



## 1. Introduction

General risk assessment of offshore plants has 2 components: risk analysis and risk evaluation. Risk analysis is subdivided into 3 steps, namely, scenario identification, frequency analysis, and consequence analysis. The process of risk assessment for offshore plants includes 2 parallel methods: a scenario-based risk assessment and a quantitative risk assessment (QRA). The former focuses on the evaluation of the risk acceptability of each identified scenario with respect to damage to the humans, environment and asset; the latter focuses on the aggregation of risks for individuals from all scenarios, including occupational and transportation risks, in order to estimate quantitative individual risk (IR) (Total, 2008). In scenario-based risk assessment, event trees are developed through stepwise refinement using all available data given by different project phases. On that basis, a risk screening matrix is applied to conduct risk evaluation iteratively by considering risk reduction measures, addressing risks to humans, environment and asset. In the same manner, a QRA is carried out according to the same approach to analyze the frequency and consequences of all identified scenarios. However, unlike scenario-based risk assessment, QRA estimates potential loss of life (PLL) for each event-tree outcome by using the results of consequence analysis, and summarizes a total risk to individuals by aggregating the PLLs (Total, 2008).

Conventionally, a suite of independent risk analyses, specifically safety studies, are carried out as a part of a QRA. These studies include fire risk analysis (FRA), explosion risk analysis (ERA), dropped object risk analysis, and others. Most of these dedicated studies will be used as inputs to the QRA and scenario-based risk assessment, or alternatively, they can provide direct inputs to engineering and design development. For example, FRA can provide some results of fire consequence modeling such as heat flux contours, flame length and pool diameter, and those data can be used to estimate the probable PLL in conjunction with the manning distribution on board. Additional applications of the above

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safety studies for risk assessment can be found, though they are not addressed in detail in this paper. Instead, this paper concentrates on the role of FRA in relation to engineering and design development during a project. With respect to that part, the purpose of FRA is to calculate the design accidental load (DAL) or to determine the passive fire protection (PFP, or a similar protection) required for critical targets such as topside safety equipment, structure frames, living quarters (LQ), and others.

There are a number of routine FRA procedures used for checking the safety of topside structures probabilistically. These procedures have different approaches and depths of analysis according to the phases of a project for which they are to be utilized. In the basic engineering stage, the FRA will be limited to a simplified analysis, because the available input data, for example a 3D CAD model, is restrictive. The typical FRA approach in the basic engineering stage is the flame-size-based one reported by Krueger and Smith (2003). It assesses the failure of a critical target by using a design flame size obtained from simplified fire consequence modeling. However, this approach, with its simplified modeling, can calculate only a rough required PFP area. In the course of detailed design, an advanced FRA is required for calculating a more comprehensive DAL or required PFP area (Jin and Jang, 2015). Recently, SCI (2009) presented a method for calculating the DAL probabilistically from the point of view of topside structural safety. However, Jin and Jang (2015) states that there are some problematic issues when using the calculated DAL to perform structural analysis. They proposed, alternatively, a new FRA procedure incorporating a cumulative failure frequency (CFF) concept. As addressed by the authors, CFF is a straightforward tool for identifying the probable failed area of critical targets, and thus it can readily be used for PFP determination. However, from a structural design perspective, structural engineers might be more familiar with some common types of data such as temperature or heat flux than with CFF. CFF may not be a type of intuitive output for structure engineers to recognize the impact of fire events quantitatively. Hence, if it was possible to identify the potential failed area of critical targets with some common data, engineers will be able to handle the failure of critical targets more intuitively. In this circumstance, this paper proposes a new FRA procedure that includes an alternative risk analysis method, namely, temperature exceedance curve (TEC). TEC is designed on the basis of the existing CFF-based FRA procedure for the purpose of calculating a design temperature distribution. Similarly to CFF, the design temperature can be applied to identify the failed area of critical targets so as to determine the required PFP area probabilistically. Beyond that, the TEC method is also intended to verify the failed area results obtained by the existing CFF method (Jin and Jang, 2015). In this paper, it is advocated that the number of input scenarios probably can affect FRA accuracy, even if carried out by a CFF-based procedure. In this regard, the TEC method can be applied as an alternative means of cross-checking with the existing CFF method to doubly guarantee the FRA result, thereby improving the accuracy.

According to the existing procedures, it is concluded that the introduction of 3D CFD fire simulation to FRA will have certain benefits from the standpoint of a detailed fire consequence analysis, but will also have a negative effect on the efficiency of FRA. When the number of input scenarios for minimizing FRA error increases, the total computing time required for CFD fire simulation will also increase significantly, leading to a conflict between accuracy and efficiency. To mitigate this contradiction, and also, to find a reasonable solution, the present study utilized an artificial neural network to approximate the results of consequence analysis, which otherwise would have been performed by a long-duration CFD simulation. With this approximation approach, it is possible to carry out the consequence analysis with a reduced number of fire simulations. Beyond that, the calculated approximation model is readily employed as a further investigation of the influence of the number of input scenarios on FRA, to which end, the above-introduced TEC method also can be applied for cross-checking with the existing CFF and finding an appropriate number of input scenarios. This paper presents an application of the proposed procedure to an example semi-submersible drilling rig. In case of fire events related to topside hydrocarbon release, the living quarters (LQ) on the semi-rig are used as a temporary refuge for humans wherein they can protect themselves from the high levels of heat flux caused by the fire events. Therefore, guaranteeing the structural safety of the LQ is essential. Usually, the safety can be enhanced by some insulated protection applied to the LQ wall surface, and it will be better if the application area is predictable to reduce the cost. However, with current practices, that may not be accomplished. In the current practices, a decision making on the needs of protection is done by a couple of CFD simulations, and for doing so, some dimensioning fire scenarios are needed. Dimensioning fire scenarios can represent all possible scenarios that may occur to be used in consequence analysis. Currently, they are determined by a qualitative risk analysis, which may involve some engineers' subjective judgement or uncertain data from previous projects. When deciding whether a protection is necessary, those dimension fire scenarios are contributing. They can be used to check whether the resultant consequences can exceed a certain threshold or not. However, the problem is that the current practices cannot offer any information on finding a proper protection area, as the protection is decided to be necessary. Regarding the protection area, there is not any further analysis in the current practices, but conservatively deciding to apply the protection to the whole surface, and this kind of choice usually increases the cost. With respect to an optimized protection area, this paper illustrates how to use the proposed procedure to predict it.

## 2. Proposed FRA procedure

FRA is one of the safety studies carried out as a component of QRA. The purpose of FRA can be summarized in 2 aspects. Firstly, it can provide some useful results of consequence modeling to the QRA, and secondly, it can be used for calculating the DAL or required PFP (or a similar protection) area of critical targets for engineering and design development. Regarding these purposes, this paper proposes a new FRA procedure, illustrated in Fig. 1. The flow diagram is built on the basis of the existing procedure (Jin and Jang, 2015). The proposed procedure includes 4 steps as summarized in Table 1. The first 2 steps are almost in accordance with the approaches adopted in the existing procedures. The main differences are appeared in Steps 3 and 4, which include some new approaches and methods that are proposed in this paper. Two key points can summarize the novel features of this procedure. The first one is the adoption of an approximation model in fire simulation for reducing total computing time in Step 3, and the second one is the proposal of the TEC method for cross-checking FRA results with the existing CFF method.

The purpose of the TEC method is to determine the necessary PFP area intuitively with a familiar physical quantity, namely, temperature and to cross-check the results with the existing CFF method. Step 4 in Fig. 1 illustrates that both of the 2 methods can estimate the necessary PFP area. This implies that the proposed TEC method should be in accordance with the existing CFF method to produce the same results. In Section 4, a case study regarding the validity of TEC method is presented. In that case study, the necessary protection area estimated by the 2 methods respectively, are compared and discussed in detail. Beyond that, a typical issue of FRA study is also mentioned, which concerns whether the