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A method for determining fire accidental loads and its application to thermal response analysis for optimal design of offshore thin-walled structures

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ABSTRACT

More than 70% of accidents that occur on offshore installations stem from hydrocarbon fire and explosion, and as they involve heat and blast effects, they are extremely hazardous with serious consequences in terms of human health, structural safety and the surrounding environment. To prevent further accidents, substantial effort has been directed towards the management of fire and explosion in the safety design of offshore installations. The aim of this paper is to present a risk-based methodology procedure to help determine the fire accidental design load of an offshore installation (AL Living Quarter) in association with the thermal response characteristics for structural optimisation. A probabilistic sampling approach with numerical fire simulations was taken to determine the fire accidental load. To determine the optimisation of the thin-walled structures of the living quarter, an A60 based on the results of thermal response analyses was conducted and the temperature distribution calculated. The analysis results suggest incorporating both the design and safety planning aspects of offshore Living Quarter.

1. Introduction

Oil and gas are important sources of energy and are mainly produced in demanding oceanic and industrial environments with significant fire and explosion hazards. The topsides of offshore platforms are the structures most likely to be exposed to hazards such as hydrocarbon fire and/or explosion [1,2]. More than 70% of accidents that occur on offshore installations stem from hydrocarbon explosions and fires that involve blast effects and heat, and are thus extremely hazardous with serious consequences in terms of human health, structural safety and the surrounding environment [3]. Fig. 1 shows examples of such accidents. The most significant fire and explosion events are those associated with hydrocarbon leaks from flanges, valves, seals, nozzles, etc. [4,5].

Developing proactive measures to prevent the escalation of such events thus requires detailed knowledge of the related phenomena and their consequences. The concern over the risk of fire is reflected in the current rules and designs for quantified risk assessment. Adequate guidelines must be established for the assessment and management of risk [6–15].

Generally, risk is defined as a product of frequency and consequence. Thus, the main task is to accurately calculate the frequency and consequences of specific events within the framework of risk assessment and management. Structural design and safety assessment both require the identification of the characteristic actions and action effects of fire [16,17].

The thermal characteristics of steel are the main factors affecting structural integrity in fire. Many researchers and reports have identified that temperature varies with the thermal and mechanical properties associated with various steels and steel structures during fires. In the conventional fire safety design of steel structures [11,14], it is usually assumed that a fire will heat every area of a structure with the same intensity. The heat intensity in terms of the heat flux is considered to remain the same throughout the duration of a fire. However, this approach is too simplistic and does not describe the actual physics, which also involve time- and space-variable radiation and convection. These factors result in continuous changes over time in the amounts of combustible gas in fires.

The conventional fire safety design approaches are essentially composed of a series of regulations, standards and procedures. They must therefore be supplemented by integrated fire safety design approaches that are in principle based on performance. Integrated fire safety design requires taking advantage of fire computational fluid dynamics (CFD)

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Fig. 1. The Piper Alpha (left) and Deepwater Horizon (right) accidents.

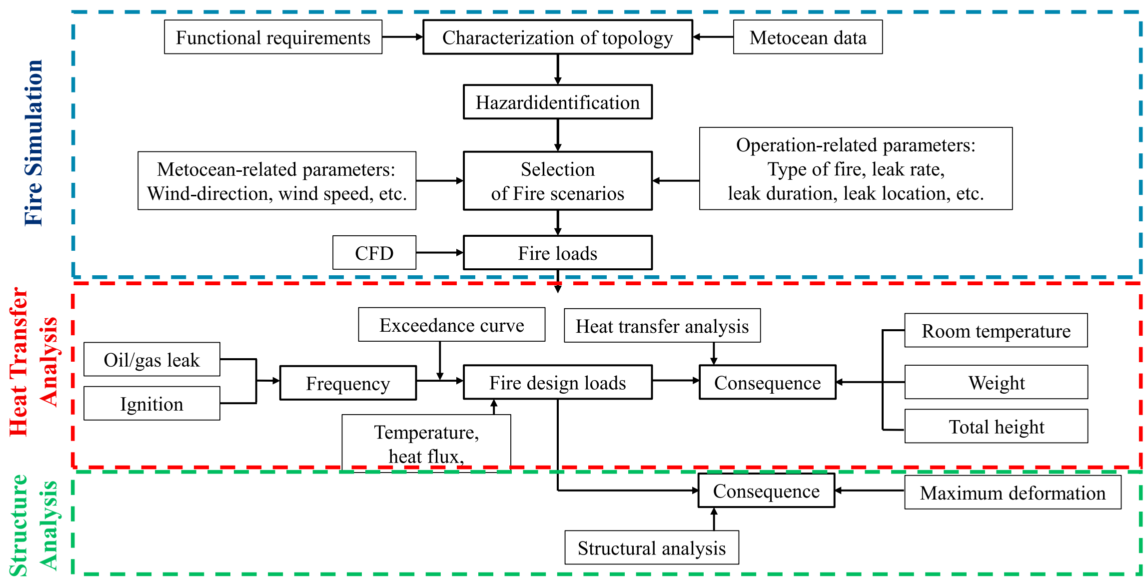

Fig. 2. Flow chart of the design process.

simulations and nonlinear structural response analyses [18,19].

Researchers have recently suggested that these procedures for quantitative fire risk assessment and management are associated with nonlinear structural response analyses, and have provided some examples [20–26]. However, this approach has only been considered and examined in terms of steel frame structures in offshore platforms. The topsides of offshore platform typically include various modules (living quarters, process modules, drilling modules, etc.) and their layout and arrangements must be considered in terms of functional and safety requirement. Most structural modules consist of basic structural members (beams, columns, plates, etc.), but living quarters are often thin-walled structures (made from unstiffened or stiffened plate). The effect of accidental design load and thermal response during fire should therefore be identified.

The objective of this study is to present a procedure for determining fire accidental loads and thermal response analysis that is suited to the integrated fire safety design of offshore thin-walled structures (living quarters). In this paper, the following are considered.

a. An introduced risk-based optimal design procedure and fire risk-based design method.
b. Fire accident simulation (Process and Utility area of the target offshore installation): to define the design fire load, a quantitative risk assessment (QRA) using KFX is conducted and the exceedance curves of temperature and heat flux are proposed.
c. Heat transfer analysis of the AL thin-walled fire wall of Living Quarter: to characterise the temperature distribution in the thin-walled structures under the design fire load, heat transfer analyses in steady and transient states are numerically conducted.
d. Optimisation of AL thin-walled structures: to optimise the total height, a design of experiment (DOE) method, specifically a central composite design with a response surface method, is performed based on the minimum temperature in a room of the thin-walled living quarters, with a structural deflection.

2. Optimal design of offshore thin-walled plates (living quarters) due to fire

2.1. Risk-based optimal design procedure

This paper introduce fire design methodologies for offshore AL thin-walled plate structures (living quarters). Fire loads are characterised by CFD simulations, followed by analyses of heat transfer and nonlinear structural responses.

Fig. 2 presents the procedure for a quantitative fire risk-based design method, as considered in the present study. Risk is defined as a product of frequency and consequence. Thus, the main task is to accurately calculate