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Operational risk assessment of offshore transport barges

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ABSTRACT

Offshore operations such as load-out/float-off, transportation and installation involve a large number of operational hazards which impose high risks on human safety and assets. During such operations, there are many situations in which transport barges and Heavy Lift Vessels (HLVs) may expose to significant hazards including structural and mechanical failures. In this work, the system of a submersible barge was reviewed based on a Hazard Identification (HAZID) technique in order to identify the worst-case scenarios during load-out/float-off operations. In addition, a fuzzy set approach was developed to quantify and assess the risk level during offshore operations of an offshore structure due to several hazardous scenarios. Rule-based fuzzy logic models were created and tested using different types of membership functions to calculate risk values, and the potential hazard impacts on the safety of crew members, the environment, the barge and the offshore structure being loaded/launched were evaluated. Fuzzy set techniques enabled a further sensitivity analysis to be conducted for the top-ranked failure modes. Overall, the paper contributes towards the development of the current guidelines for offshore operations.

1. Introduction

Safe transportation and/or installation of offshore structures such as steel jackets and jack-up units is one of the greatest challenges in the offshore industry. These structures are transported offshore either by dry- or wet-tows. In severe weather conditions, the likelihood of transportation accidents which include grounding, collision and loss of stability or buoyancy (Vinnem, 2007) can be extremely high which can impose high risks on human safety and assets. Among several accidents, the Marathon LeTourneau (Denton, 1989) and the West Gamma (Vinnem, 2007) jack-up units capsized when they were being towed. Another example is the loss of stability due to flooding, which led to the capsizing of the Bohai 2 jack-up rig and caused the death of 72 people. In 2006, at the CNOOC (Offshore Oil 298) project, 68 people died in a towing vessel accident during a typhoon (Fang and Duan, 2014). According to Gunter et al. (2013), offshore transportation events were the leading cause of fatalities of workers involved in offshore oil and gas operations in the US during the period 2003–2010.

As the use of dry-tow techniques has been known to be safer than wet-tows, most of load-out, transportation and float-off/launching of offshore structures are performed using barges and Heavy Lift Vessels (HLVs) (Van Hoorn, 2008). In doing so, the load-out and marine transportations of offshore structures and topside modules are usually performed in accordance with GL Noble Denton guidelines (GLND, 2005; GLND, 2009). However, such guidelines do not provide a detailed risk assessment procedure which can be used for hazard identification and risk mitigations. Nevertheless, during such operations, there are many situations in which transport barges can expose to significant hazards including structural and mechanical failures. Therefore, the necessity for developing new standards based on reliable knowledge is important towards establishing a new milestone to assess and mitigate transport barge and HLV risks.

The literature shows that most of the recent research efforts have been focused on risks of conventional ships and offshore structures. On the other hand, the safety of barges and HLVs has received less attention. It is, therefore, important to assess the possible consequences of hazards

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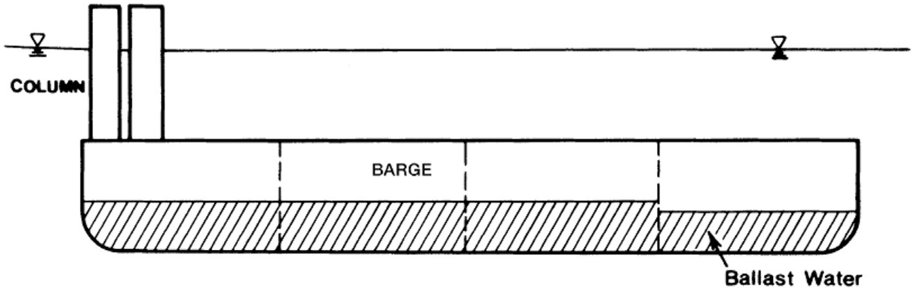

Fig. 1. A submersible barge with two stabilised columns (Gerwick, 2002).

Table 1
Typical dimensions of submersible barges.

Overall length, L_{OA}	80–160 m
Breadth	0.20–0.33 L_{OA}
Depth	0.07–0.08 L_{OA}

on the operation and safety of offshore transport barges.

Currently, there are numerous methods used for marine and offshore risk assessment, which can be broadly categorised into quantitative and qualitative approaches (ABS, 2000). Quantitative risk assessment (QRA) techniques have been regarded in the industry as the only reliable sources (Wang and Pedersen, 2007). However, due to limitations with accident/incident reports about the likelihood and severity of transport barge and HLV hazards, the application of QRA techniques would be difficult. On the other hand, qualitative risk assessment approaches such as the risk matrix technique assess the risk in descriptive terms by using experts' opinions. The use of the risk matrix has been adopted with the assistance of experts' opinions from the offshore and shipping industries whose decisions on the degree of hazard are usually based on their experience in the field (Aronsson, 2012). Experts often use Hazard Identification (HAZID) and Hazard and Operability (HAZOP) techniques in order to cover a wide range of possible hazardous scenarios (Spouge, 1999). The likelihood and consequence associated with a failure mode are weighted based on the experts' knowledge and combined by the risk matrix to obtain the risk level/index (Spouge, 1999; ABS, 2000). This implies that the results of qualitative risk assessment techniques are experts' knowledge dependent "subjective". Furthermore, the risk results obtained by these techniques are not often reproducible due to an uncertain risk level. One more limitation with the application of qualitative risk assessment techniques is that they rely on the use of discrete attributes, which do not account for uncertainty or vagueness of a hazardous scenario (Elsayed, 2009).

Recently, the use of fuzzy logic in artificial intelligence applications such as expert systems has been increasing. Fuzzy logic is a mathematical tool for modelling inaccuracy and uncertainty of the real world and human thinking in which variables have degrees of falsehood or truthfulness represented by a range of values between 0 (false) and 1 (true). Unlike binary systems, the outcome of an operation is expressed as a probability in fuzzy logic systems. For instance, the outcome may mean "probably true", "possibly true" or "probably false". Fuzzy logic based approaches have recently been used for different engineering problems such as risk assessment of LNG carriers (Elsayed, 2009; Elsayed et al., 2014), risk management of seaports and terminal (Mokhtari et al., 2012) and expert systems (Samantra et al., 2014).

Elsayed et al. (2009) developed a fuzzy inference system to assess risks of LNG carriers during loading/offloading operations at terminals and found that the use of a fuzzy set approach is particularly suited for handling multiple attribute risk problems with imprecise data. Nwaoha et al. (2013) developed a framework for the risks of hazards of LNG carrier operations using the combination of a risk matrix approach and a fuzzy evidential reasoning method. Stavrou and Ventikos (2016) used a process mode and effects analysis approach to evaluate different risk scenarios related to a ship-to-ship transfer of petroleum cargo operations. Zhao et al. (2015) applied a Bayesian network method to assess the risks of accidents in the anchoring system of an LNG carrier. It is worth mentioning that neither of the aforementioned studies investigated risks of offshore operations such as load-outs or float-off/launching.

The aim of this paper is to present and discuss risk assessment results of a transport (submersible) barge. In this study, load-out/float-off of an offshore structure, and the operational risks during the load-out/float-off phase were considered, whilst hazards due to weather conditions are beyond the scope of this paper. Potential hazards/operability difficulties of the system were identified using the HAZID technique. The fuzzy set approach was developed to synthesise the risk levels of the basic failure modes to enable comparisons among top-ranked failure modes. A rule-based fuzzy model using different types of membership functions was created to calculate and assess operational risks to four consequence components which include on-board barge crew members, the barge, the structure being loaded/launched and the environment.

2. Transport barges

The design of submersible barges used for offshore transportation is quite similar to that of floating dry-docks, and therefore they can be operated in floating and submersible modes (ABS, 2009). Submersible

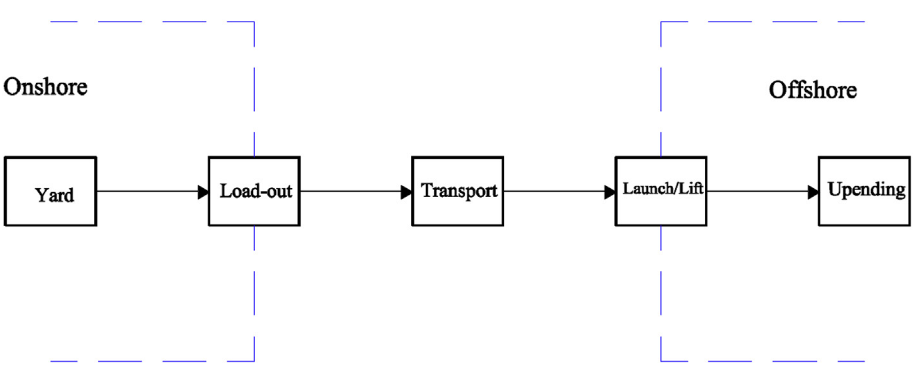

Fig. 2. Main steps of offshore transportation and installation of a jacket structure.