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An assessment of anchor handling vessel stability during anchor handling operations using the method of artificial neural networks

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ABSTRACT

The risk of vessel capsizing is inherent to anchor handling operations (AHOs). Lessons learned from the Bourbon Dolphin accident reveal that the large static heeling angle could not be prevented due to the lack of awareness of the vessel's stability status, which can be improved with the help of a suitable on-board monitoring system. Therefore, an on-board monitoring system is proposed for assessing stability in terms of the static heeling angle. However, a complete mathematical model is not available for estimating a static heeling angle as a function of operational parameters. Therefore, an artificial neural network (ANN)-based functional relationship has been established between the operational parameters and the static heeling angle. Furthermore, a parametric study has been performed to investigate the effect of neural network topology on network performance. The results show that an ANN topology that contains one hidden-layer is efficient enough to predict a static heeling angle. The correlation coefficient between the ANN model predictions and the target values is 0.999. This result shows that the ANN provides an accurate estimate of the static heeling angle as a function of the operational parameters. Therefore, the proposed mathematical model can be used for assessing a vessel's stability during AHOs.

1. Introduction

Offshore floating structures are widely used in oilfield exploration, production and accommodation. These structures are usually held in position by means of mooring systems. Typically, these mooring systems consist of components such as mooring lines (which may be a combination of chains, wires and synthetic rope) and anchors. The operations of floating structures involve de-positioning (anchor recovery from the seabed); move (towing the floating structures to a new location) and positioning (deployment of anchors into the seabed) are defined as anchor handling operations (AHOs). These operations are performed with the help of dedicated vessels called anchor handling vessels (AHV), which conduct activities such as handling mooring lines and deploying or recovering anchors. These AHOs are applied to other floating systems that are used in the offshore wind energy and aquaculture industries. However, this paper focuses mainly on AHOs that are associated with mobile drilling rigs. In practice, to ensure safe operations, the allowable weather conditions are defined in the rig move procedures.

The performance of AHVs during AHOs is judged based on two objectives, namely, the economy and safety. In this work, the latter objective is studied. Even though, to date, there have been only two accidents (Lyng et al., 2008; Nielsen, 2004) related to AHVs during AHOs, AHOs are considered to be highly risky. The risk of a vessel capsizing is an inherent part of these operations, and it is not possible to eliminate this risk, but it is possible to reduce. The risk associated with AHVs in AHOs can be managed by improving the rules and regulations, and providing the information related to the vessel's stability and control strategies to the crew based on the condition monitoring system and decision support system, respectively. More than these additional efforts are required for controlling the risk during AHOs which are like training the vessel's crew, etc.

In the aftermath of the tragic Bourbon dolphin vessel accident (Lyng et al., 2008) the IMO Sub-committee on Ship Design and Construction meeting (MSC 88/23/2) decided to establish a new international standard for the safe design and operation of tugs and anchor handling vessels, for inclusion in part B of the 2008 IS Code. The committee agreed to include criteria for anchor handling operations in their meeting at MSC 95 (June 2015). During the discussion at SDC 3 (IMO SDC 3/WP5, 2016), the working group agreed the amendments and further stated that these amendments should enter into force on 1 January 2020. The proposed amendments did not consider the wind and the current force effect on the vessel's static heeling angle and the vessel's dynamic rolling angle. To address these

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drawbacks, Gunnu and Moan (2016) proposed two stability criteria, which are 1) the critical static heeling angle criterion and 2) the critical rolling angle criterion. For a given AHV and loading condition, the above mentioned criteria depend on the vessel's dynamic rolling angle (in waves), static heeling angel and the capsizing angle. These angles depend on the operational parameters, such as the magnitude of the mooring load, the angle between the vertical axis and the mooring line, the angle of attack (the angle between the mooring line and the vessel's centreline), the control forces (exerted by the thruster and rudders in the transverse directions) and the environmental loads (due to current, wind and waves). The assessment of these angles in the analysis and planning phase could be helpful in defining the safety limits in the operating manual. Moreover, by varying these operational parameters the relationship between the vessel's static heeling angle and capsizing angle, and between the maximum critical rolling angle and static heeling angle were established.

In this study, a condition monitoring is proposed to provide the information related to the vessel's stability margin to the crew. The risk of a vessel capsizing can be mitigated by continuous monitoring of the vessel's stability margin during the operating phase and implementing correct control strategies during the execution phase of the operation which are discussed in Appendix A. Therefore, awareness of the vessel's stability status and safety margin well in advance is essential for conducting safe operations. This information is useful for the vessel's master in deciding whether to continue the operation or not. Moreover, this information is useful for making the correct decisions at the correct time. These decisions are possible to achieve by making use of a proposed on-board monitoring system that accounts for the operational parameters' effect on the vessel's stability.

An appropriate on-board monitoring system will play a major role in assessing and mitigating vessel capsizing scenarios during the operation. Currently, there are several on-board monitoring systems that are available for AHVs assessing operational parameters such environmental parameters (wind parameters from wind sensors and wave information from the rig/other resource), mooring line tension (winch monitor), the vessel position and heading, and vessel drift-off (position reference system), the vessel's heading and position with respect to the rig and target location (navigational monitor), the vessel power distribution (power monitor system), stability in loading condition (Loadicator), video screens, and more. However, none of these factors are useful for assessing the vessel's stability status when it is subjected to a mooring load during AHOs. Hence, in the present practice of AHOs, the vessel's master assesses the vessel's stability margin and further conducts the necessary actions for continuing the operation or preventing (and mitigating) critical scenarios. The efficiency of the stability prediction and the success of the actions depends on the skill, knowledge and experience of the vessel's master. Even an experienced master might not have faced all of the possible critical scenarios that are related to AHOs in his/her service. Therefore, relying only on the master's skills is not an appropriate approach. Hence, a solution to overcome this problem is currently needed. In this study, the vessel's static heeling angle is considered to be a monitoring parameter that is useful to understand or/and monitor the vessel's stability during the execution phase of the operation. This estimated vessel's static heeling angle can be compared with the vessel's critical static heeling angle (for an operating sea state) for assessing the vessel's safety margin during AHOs. This critical static heeling is possible to estimate for a given operating sea state. With this approach, the vessel's dynamic rolling angle effect on the vessel's safety is considered. However, in this study, the dynamic rolling effect is not considered. The vessel's static angle is influenced by operational parameters, such as the magnitude of the mooring load; the angle between the vertical axis and mooring load; the angle of attack (the angle between the mooring line and vessel centreline); the wind and current velocity in the transverse direction; the vessel's transverse drift velocity and the mooring line position with respect to the tow pins. During AHOs, the operational parameters vary significantly, which implies variation in the vessel's static heeling angle. However, a complete mathematical model is not available for estimating the vessel's static heeling angle as a function of the operational parameters during the operation.

Therefore, in this paper, a method has been proposed for estimating the vessel's static heeling angle during the AHOs when the vessel is subjected to the heeling moment induced by the operational parameters and the vessel's righting moment. In the present study, artificial neural networks (Golden, 1996; Haykin, 2009; Lippmann, 1987; Mehrotra et al., 1997) are used to establish the functional relationship (function approximation modelling) between the vessel's static heeling angle and the operational parameters during anchor handling operations. The ability of ANNs to compute has been proven in the field of prediction and estimation. They are suitable for modelling and solving complex problems that are difficult to solve and model with classical mathematics and traditional procedures.

The results of this study can be useful for the vessel's master and other involved personnel to understand the vessel's stability (vessels' heel) status and margin during operations. Furthermore, the proposed mathematical model can be helpful for recognizing faults by understanding the progress of the events and the factors that can have an impact on the vessel's performance in terms of safety. To prevent accidental events, the system can be set to give an alarm when the vessel's stability reaches its limit state. In real-time applications, the vessel's stability is assessed by feeding the information on the operational parameters to on-board monitoring systems. This approach saves time and resources for the vessel's master by producing an estimate of the vessel's stability status at any point in time.

This paper is organized into six sections. The next section contains a literature review of AHOs. The neural network approach is presented in Section 3. A case study is described in Section 4, and the results and discussion are given in Section 5. Finally, the conclusions of the obtained results are presented in Section 6.

2. Anchor handling operations

A typical range of AHOs and a sequence of steps associated with them are described in the operating manuals, e.g., Vryhof Anchors (1999), and dedicated books, e.g., Gibson (1999); Hancox (1994); Maudsley (1995); Ritchie (2007). These operations depend on a number of factors, such as the site location, the infrastructure on the seabed, the number of vessels, the type of mooring equipment and the weather conditions (such as significant wave height, wave period, wind velocity and direction, and the current velocity and direction). As mentioned above, one of the major accident scenarios during AHOs is vessel capsizing. The risk associated with capsizing can be prevented or mitigated by means of an appropriate vessel design, operational planning, and efficient execution of the operation.

An earlier study of accidents such as the Bourbon Dolphin (Lyng et al., 2008) and Stevns Power (Nielsen, 2004) incidents and near-misses has helped in understanding the influential factors that are related to a vessel's capsizing during AHOs. The key sequence of events related to the Bourbon Dolphin accident are discussed in Appendix A. Fig. 1 presents the influencing factors that are related to AHVs capsizing based on the study by Gunnu et al. (2010) on the Bourbon Dolphin (2008) vessel accident. As seen in Fig. 1, the main reason that causes vessel capsizing is a large angle of attack (the angle between the mooring line and the vessel centreline). This large angel of attack along with the mooring line tension and poor manoeuvring causes the vessel to develop a large static heeling angle of approximately 5 degrees, and along with this, large waves can lead to capsizing. The angle of attack depends on the vessel's position and bearing (direction) with respect to the rig. Operational features such as the vessel's behaviour in the horizontal plane, manoeuvring and tow pin handling influence these parameters. Gunnu and Moan (2012) studied how the angle of attack rapidly changes in various thruster capacities and current headings.

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