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Failure analysis of naval vessel's mooring system and suggestion of reducing mooring line tension under ocean wave excitation

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ABSTRACT

A moored ship can experience problems when subjected to heavy environmental loads. In most cases, wind and current loads are the only design considerations for the mooring situation in the harbor, and wave loads are not considered due to the low wave amplitudes in harbors. However, many new harbors are constructed near the open sea, and entrance channels are being built deeper and wider than the classical harbors. So, many cases of mooring failure due to heavy wave loads are recently being reported in harbors. In this paper, failure analysis has been performed on a ship in harbor with mooring failure. The failure analysis results demonstrated that the wave drift forces can cause failure of the mooring system. Therefore, consideration for new design of mooring system, which considers the wave loads, is suggested.

1. Introduction

The safe mooring of vessels in the harbor depends on a variety of characteristics, such as the type of mooring line, mooring methods, design and installation of bitts, bollards, fairleads, and foundations. The mooring safety should be ensured while the ship is exposed to heavy environmental loads such as wind, current, and wave forces. There are numerous standards, guidelines, and recommendations in marine industry concerning the mooring equipment and mooring fittings. The most widely used standards are the Oil Companies International Marine Forum (OCIMF) [1] for commercial ships and the Unified Facilities Criteria (UFC) [2] for naval vessels. These standards provide calculation formulas for the wind and current loads of the moored ship. However, the calculation of wave force is mostly neglected in the designing stage, due to the small wave heights in harbors. Nowadays, many new harbors are being constructed near the open seas, and the entrance channels are built deeper and wider than the classical harbors, because the recently constructed ships are very large compared to the classical ships. In the ocean facing ports, many mooring system failures have occurred, such as mooring line breakage and fracture of bitt foundation structures. Therefore, it is very important to predict the ship motions and mooring forces according to the wave excitation.

To predict the wave forces, analytical methods or numerical methods can be selected. Wilson [3] presented the concept of the ship and its mooring system as a spring-suspended mass system, to analytically predict the mooring force under the standing wave. Abramson and Wilson [4] obtained solutions to the equation of motion, developed by Wilson, to determine the amplitude response of a ship moored in a standing wave by neglecting the damping. Kilner [5] analyzed the case of a ship mooring line, which has non-linear characteristics, and obtained an approximate solution to the nonlinear problem by neglecting the damping. Raichlen [6] dealt with the wave-induced motions of moored small vessels, considering the nonlinear characteristics of the mooring rope or the linear theory. This considers the response of the body as a single-degree-of-freedom, describing that the surge motion for standing waves is used to obtain the amplitude response. Also, there are several commercial software that numerically predict the mooring forces, such

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as TERMSIM, BAS, and SHIPMOORING. These products are based on the impulse response technique, which was suggested by Cummins [7]. Recently three-dimensional methods are developed by using the panel method, also known as the boundary integral equation method (BIEM) which was developed by Hess [8]. Using the panel method Lee [9] developed the frequency domain approach and Bingham [10] developed the time domain approach. And van der Molen [11] analyzed the moored ship motion in time domain including the nonlinear ocean wave response.

In this paper, failure analysis was performed for the fractured mooring system of a typical naval vessel. Through the visual investigation, it was estimated that the fracture was caused by the extreme external force. Hypotheses to analyze the various possible cases of environmental conditions are presented. To analyze the hypotheses, the current and wind loads were assumed as a static force. Wave motion was derived by the time domain approach using the linear shallow water ocean wave theory by simplifying the wet body as a barge, which was suggested by Cummins [7]. And wave drift force was calculated by solving the equation of motion using the Runge–Kutta 4th order method. These calculated static and dynamic forces were used as the external force to identify the distribution of the stress on the bitt foundation plate and fairlead bolts, under various extreme conditions. Finally, based on these failure analysis results, methods are suggested for the prevention of mooring system fractures.

2. Investigation of the fracture

To investigate the failure of the fracture, the failure analysis was conducted in accordance with the guidelines of VDI 3822 [12]. The resulting failure analysis logical tree is shown in Fig. 1.

The mooring system failures occurred, which is as shown in Fig. 2, by the fraction of the bitt foundation plate and the bolts used to fix the fairlead. Bitt and fairlead are installed on the deck structure, as shown in Fig. 3(a). Bitt is installed on an FRP foundation plate as shown in Fig. 4(b). Mooring line tension can increase the bending moment of the bitt foundation plate and the shear force of the blots used to fix the fairlead.

Through the visual investigation on the fracture mode of bitt foundation plate, delamination can be found in the upper surface of the fracture; on the other hand the lower surface has a clean cut out surface without delamination (Fig. 4). These investigations suggest that the upper surface was subjected to compression and the lower surface was subjected to tension, which is the typical sign of the bending moment failure of the composite plates. The bolt used to fix the fairlead (Fig. 5) was analyzed using the Scanning Electron Microscope (SEM), which was fractured at almost the same time as the foundation plate; typical sign of shear fracture such as spiral deformation texture and dimples was found and there was no significant sign of fatigue, such as beach marks. Based on the aforementioned investigations, it can be estimated that external forces caused by environmental conditions, such as wind, current, and wave, can cause fractures to the mooring system.

The naval vessel should be designed and constructed by the manufacturer to safely resist the environmental load conditions of UFC 4-159-03 [2]. Therefore, the following fracture hypotheses can be deduced.

Hypothesis 1. The mooring system is not designed sufficiently to resist the environmental conditions of UFC 4-159-03 (design load).

Hypothesis 2. The fracture was caused by environmental load exceeding the condition of UFC 4-159-03 (design load).

If Hypothesis 1 is true, it can be concluded that the failure was caused by the underdesigned mooring system. If Hypothesis 2 is true, it can be concluded that the design criteria are not sufficient for the safe mooring of the naval vessel. In order to verify the above hypotheses, the wind, current, and wave force that are possibly acting on the mooring system are defined in Section 3, and the structural analysis was performed under these conditions in Section 4.

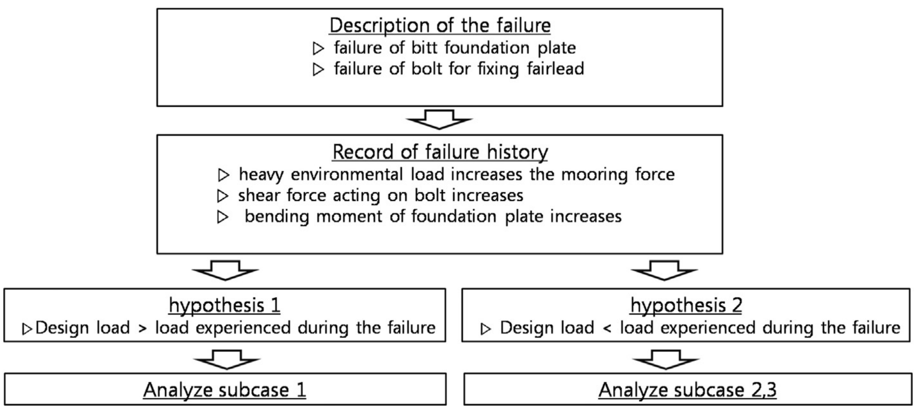

Fig. 1. Failure analysis logical tree for the mooring system.