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Structural Reliability Analysis for Assessment of Ultimate Limit State of Ship's Hull—A Case Study

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The aim of this paper is to establish a procedure of Structural Reliability Analysis (SRA) for the assessment of the Ultimate Limit State (ULS) of a ship's hull. Probabilistic models of both load (wave-induced bending moment) and capacity (hull girder ultimate strength) have been derived by using direct calculation methods based on the latest analyzing techniques. An implemental procedure of SRA has been proposed for estimating the ULS of typical merchant ships. As application examples, a series of SRA has been performed by using the First Order Reliability Method (FORM), and the annual failure probability of tanker, bulk carrier and container carrier for hull girder ULS has been calculated. It is found from the SRA results that the predominant condition of a tanker (VLCC) is the full loading and sagging condition, and the other conditions seem to be negligible. In the case of a large bulk carrier, the hogging condition is also important because of the local load effect by sea and cargo pressures together with the sagging condition. Contrary to the previous 2 cases, the full loading and hogging conditions are very influential in a large container carrier. Based on the obtained failure probabilities of these ships, a reference value of the target failure probability for ULS assessment by using the SRA procedure is noted.

INTRODUCTION

Recently, goal-based new ship construction standards (GBS) have been discussed by the IMO (International Maritime Organization). In such a situation, the IACS (International Association of Classification Society) will also come to consider the development of a set of more refined rule formulation based on GBS by using structural reliability analysis (SRA) in the future. The aim of this paper is to establish an SRA procedure for the limit state assessment of a ship's hull.

There are 4 important limit states to be considered in the assessment of ship structural safety: Serviceability Limit State (SLS), Ultimate Limit State (ULS), Fatigue Limit State (FLS) and Accidental Limit State (ALS). Among these, the hull girder ULS is the most critical failure mode, as the collapse of the ship's hull will directly link to the loss of lives and properties, and as the oil spill will lead to significant marine pollution. Thus, this paper presents the SRA procedure for the assessment of hull girder ultimate strength of the ship's hull using the latest analysis technologies.

Until now, much research on SRA for hull girder ULS assessment has been carried out (SSC, 1990; ISSC, 1991, 2000; Mansour, Wirsching and Luckett, 1997). In these studies, the probabilistic models of both load and capacity for SRA have been derived by using practical simplified analysis or closed formulae. Further, a comprehensive investigation of a semiprobabilistic format for the ULS assessment of ships has been carried out considering the effect of ship operations on loads (Moan, Shu, Drummen and Amlashi, 2006). Although the application of direct calculation methods calls for much computing cost, due to the recent rapid progress of both computer hardware (CPU) and software (analysis technologies), this application has become practically feasible to some extent (Ostvold, Steen and Holtmark, 2004; Fujikubo and Pei, 2005; Harada, 2005).

In this paper, by using the latest analysis technologies, refined SRA has been performed for the ULS assessment of the ship's hull. Regarding the probabilistic load model, that is, the wave-induced bending moment, the response of ship motion in regular waves has been obtained by using series analysis by the strip method, and long-term prediction has been made based on long-term statistics of wave data; the probabilistic model of extreme wave-induced bending moment has then been derived. Regarding the capacity model, that is, the hull girder ultimate strength, series calculation by using nonlinear FEA with one transverse framing model for a ship cross-section has been performed systematically, changing dominant parameters on hull girder ultimate strength—thus deriving a more accurate probabilistic model of hull girder ultimate strength. Further, the model uncertainties (the difference between estimated values and true values) of both load and capacity estimations have been considered in the models and a refined ULS format for SRA has been proposed.

Series SRA have been performed by using the First Order Reliability Method (FORM), and the annual failure probability for the ULS assessment of the ship's hull has been obtained. Based on the SRA results, the reliability level for ULS of some existing ships has been clarified, and allowable criteria for determination of the target failure probability for future Safety Level Approach (SLA) in GBS has been noted.

PROBABILISTIC MODEL OF WAVE-INDUCED BENDING MOMENT

The authors have performed many direct load analyses for the development of practical design loads for various merchant ships (Shigemi and Zhu, 2003). Based on the results, the probabilistic model of the extreme wave-induced bending moment has been derived here.

Long-term and Short-term Predictions of Wave-induced Bending Moment

At first, ship response in regular waves is calculated by using the strip method. Fig. 1 shows response amplitude operators

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KEY WORDS: Structural reliability analysis (SRA), ultimate limit state (ULS), First Order Reliability Method (FORM), wave-induced bending moment, hull girder ultimate strength, annual failure probability.