Experimental Research on Fatigue Strength and S-N Curve Fitting of Special Structural Joints of Ships

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ABSTRACT

In this paper, the S-N curves' characteristics of structural joints of the example ship were studied through real scale model fatigue experiment. The key areas with serious fatigue problems were identified through finite element calculation, from which three joints with special structure form were selected as the research objects of this experiment. The fatigue experiment models were designed and the fatigue strength experiment of each joint under multiple load conditions were conducted. The fitted P-S-N curves for each joint were fitted on the basis of the experimental results. The fitted P-S-N curves were applied to the fatigue strength assessment of the joints, and the results were compared with those obtained by the existing CCS S-N curves.

KEY WORDS: Typical joint; real scale model; fatigue experiment; direct calculation method of spectrum analysis; joint selection; S-N curve.

INTRODUCTION

Fatigue failure is one of the main failure forms of marine structures (Clark, 1991). For many years, the fatigue fracture of ship structure has been concerned as one of the most significant problems in shipbuilding industry (Jordan and Knight, 1980). One of the key issues in fatigue assessment is the selection of suitable S-N curves. For some specific structural forms of ships, the absence of suited S-N curves in the existing classification society rules had largely reduced the accuracy of fatigue strength assessment. To solve this problem, it is necessary to determine the S-N curve characteristics for particular structural forms by model experiment. Also through the fatigue experiment under simulated real load and environment, the fatigue characteristics of the structural components could be correctly evaluated, and the expected effect of the fatigue analysis could be verified.

1. SELECTION OF FATIGUE EXPERIMENT JOINTS

The spectrum analysis direct calculation method of fatigue assessment is a widely accepted method which can truly reflect the fatigue performance of ship hull (Tran, Garbatov and Guedesm, 2013). The wave loads are computed by calculation software and applied to the finite element structure to obtain the fatigue stress response and stress range, and then the fatigue life of the structure can be acquired through the calculation of cumulative damage degree (Guedes and Moan, 2016).

In this study, a certain type of ship with complex structure was selected as the research object. The steel (CSSB) with yield strength of 235 N/mm\(^2\) was used as the structural material of the ship hull, and high-strength steel (CCSDH32) with yield strength of 315 N/mm\(^2\) was used for some parts of inner hull plate, deck plate and some strong stiffeners. The material density \(\rho =7850\ \text{kg/m}^3\), the elastic modulus \(E=2.06 \times 10^{11}\ \text{N/m}^2\), and the poisson ratio \(\nu =0.3\). The main dimensions and related parameters of the ship were shown in Table 1. The finite element model of the whole ship was established (as Fig. 1). A total of 1523 finite element nodes related to fatigue strength assessment were selected in the model, which covered all types of typical nodes of the whole ship, and all nodes were classified according to their structure type. The spectrum analysis method was adopted to calculate the fatigue strength of the whole ship. 5 typical loading conditions of the example ship (normal displacement, full load displacement, empty displacement, displacement of returning to the port, maximum displacement) were selected as the working condition (each time distribution coefficient \(\alpha =0.2\)). The wave loads were calculated by Compass-Walcs-Basic, a wave load calculation software of China Classification Society (CCS) based on three dimensional potential flow theory, which is developed by Institute of Mechanics of Harbin Engineering University. Because of the excellent performance in accuracy and practicality, WALCS is widely used in the calculation of hull structure motion (including speed and acceleration) and wave load response under various sea conditions for both floating body without speed and ship with normal speed, and make long-term and short-term prediction of wave load based on selected sea condition data. The software includes several modules such as BASIC, LE and NE, among which BASIC is a three-dimensional linear frequency-domain solution module, LE is a three-dimensional linear hydroelastic module, and NE is a nonlinear hydroelastic time-domain module. The BASIC module of WALCS was mainly used in this research. The stress response transfer functions and stress response spectrums of the hull structure in each regular wave were calculated by applying wave load to the finite element model of the ship hull, and the cumulative fatigue damage degrees and fatigue lives in the 20-year fatigue recovery period were finally obtained (Thurlbeck, 1991). The nodes with the shortest fatigue life among all node types were sorted...