A Crack Propagation Life Calculation Method for Thick Plate Structures of Ultra-Large Container Ships

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ABSTRACT

A fracture mechanics based fatigue crack propagation life calculation method for ultra-large container ships is developed. A deformation decoupling method is proposed for stress intensity factor calculation to reduce the computation. Spectral analysis method is introduced for crack propagation simulation. The long-term process of structural response of the hull under wave loading is split into short-term processes, and various sailing conditions can be considered. An example and validation are carried out.

KEY WORDS: Fatigue crack propagation; spectral analysis method; deformation decoupling; thick plate; random wave load; ultra-large container ship.

INTRODUCTION

Ultra-thick steel plate (up to 85mm) is widely used in ultra-large container ships. The S-N curve method cannot accurately predict the fatigue life of thick plate structures. Fatigue assessment methods based on fracture mechanics have been developed. It is a key new direction to address the problem. This has two aspects to be solved. The first is the method for calculating the stress intensity factor at the crack tip. The second one is the realization of fatigue crack propagation under random wave loading.

For the first aspect, the weight function method was proposed for stress intensity factor calculation by Bueckner (1970) and Rice (1972) in the 1970s. Each different structural form has its own independent expression for the weight function, which is less generalizable. The most widely used in engineering is the empirical formula method. Many scholars have done a lot of work in this area, for example, the formula proposed by Newman-Raju (1981) for calculating the stress intensity factor of surface cracks in flat plates has been widely used by major rules. The finite element method is mainly used to solve the stress intensity factor in complex structures and complex stress fields. The finite element method has the highest generalizability and accuracy. However, considering the complex alternating loads with long-term crack expansion, the high computation is a problem that cannot be ignored.

For the second aspect, Sumi et al (2014) used a storm model to investigate the crack propagation life prediction of buried cracks in high-strength thick steel plates. The results show that the load sequence has an important effect on fatigue crack propagation. Zhang et al (2018) obtained the fatigue load distribution in each short term by the spectral analysis method and obtained the life-time load sequence by the random generation method for the fatigue crack propagation calculation of the hull structure. Soares (2005) analyzed various uncertainties in the short-term response and long-term response of wave loads for North Atlantic sea state and global sea state. Moan et al (2005) analyzed the statistical characteristic of the significant wave height with time and performed an uncertainty study on fatigue loads and local stresses. Among them, the method combining spectral analysis with fracture mechanics is the most accurate. In the process of fatigue crack propagation, the size and shape of the crack change constantly. Therefore, the linear relationship between stress intensity factor and hot spot stress is broken. The accurate stress intensity factors only can be obtained by continuous mesh reconstruction. Or the stress intensity factor can be calculated by empirical formula to ensure the calculation efficiency. Efficiency and accuracy cannot be balanced to some extent.

In this study, a stress intensity factor calculation method based on structural deformation decoupling is proposed. This method can obtain accurate stress intensity factor transfer function under the condition of countable FEM calculations of structure with crack. Then, the load spectrum can be transformed into the stress intensity factor spectrum by the spectral analysis method, and the distribution function of the stress intensity factor is obtained. The short-term crack propagation length is calculated from Paris formula. Long term crack propagation is composed by numerous short-terms superposition. A typical spot at a hatch corner of an ultra-large container ship is taken as an example to verify the feasibility of the method.