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Spectral-based fatigue crack propagation prediction for very large floating structures

Tao Qi[a], Xiaoping Huang[a,b,*], Liangbi Li[b]

[a] Collaborative Innovation Center for Advanced Ship and Deep-sea Exploration, Shanghai Jiao Tong University, Shanghai, 200240, China
[b] Institute of Ocean Engineering, Jiangsu University of Science and Technology, Zhenjiang, 200135, China

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ABSTRACT

This paper provides a fatigue assessment for a very large floating structure using a spectral-based fracture mechanics approach that combines hydrodynamic response analysis, spectral stress intensity factor calculation, load spectrum, and fatigue crack propagation model. To predict fatigue crack growth in the critical welded joints, this paper summarizes formulas associating equivalent stress intensity factor range with equivalent stress range of a given hot spot. Both are performed using spectral analysis in stochastic sea conditions. The unique curve model is introduced for crack propagation prediction. Thus, this paper provides a reasonable way to convert complex wave loads into crack growth, and can be widely applied to other marine structures.

1. Introduction

Very large floating structures (VLFSs) are artificial floating land parcels on the sea. VLFSs are designed primarily for floating airports and ports, and for calm waters on the coast or on open sea, with length and width at least 1000 m. VLFS may be classified into semisubmersible or pontoon type, depending on their geometry. Semisubmersible VLFSs have a platform raised above sea level supported by columns and are suitable for deployment on the open sea, whereas the pontoon VLFS platform rests on the surface and is intended for calm waters [1–3].

Like conventional marine structures, VLFSs are exposed to severe seas and long term wave loads. Wave induced stresses are the main source of fatigue damage. Research on VLFS wave response has increased recently. Shigeo Ohmatsu [4] overviewed and categorized estimation methods for VLFS hydroelastic behavior. Although VLFS scale may be an order of magnitude greater than previous floating structures, the basic technology required for their design is similar because each single module a VLFS is conventionally sized. Several papers have provided methods to predict motions and inter-module forces for VLFSs [5,6], and numerical analysis based on three dimensional (3-D) potential theory has been shown to be an effective approach. Therefore, this paper investigates fatigue damage based on AQWA (an engineering analysis suite of ANSYS) to obtain the response amplitude operators (RAOs) and wave loads for VLFSs [7]. And the quasi-static method has been adopted in this paper for the response analysis of the VLFS in waves.

Fatigue damage assessment is mainly based on cumulative fatigue damage (CFD) theory or fracture mechanics. However, S-N curve approach (CFD) cannot provide crack growth or residual fatigue life. On the other hand, fracture mechanics is particularly useful once when an initial flaw has been found in the structure. So the fracture mechanics method is intended to be applied for determining the residual life in cases where cracks are detected and sized during service. Therefore, Combining with fracture mechanics approach, this paper presents a spectral-based fatigue life prediction method for semisubmersible VLFSs which is assumed

* Corresponding author.
E-mail address: xphuang@sjtu.edu.cn (X. Huang).

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with an equivalent initial crack size. For having a comparison of the result with that of by S-N curve approach, an equivalent initial crack size is defined by calibrating the results by fracture mechanics model and by a relevant S-N curve. Strictly speaking, there is no comparable of the fatigue lives calculated by this two methods respectively. And there are many of factors affect the equivalent initial crack size. This issue will be discussed in the future study.

Global strength assessment [7] shows that VLFSs are more susceptible to damage by wave loads than ordinary platforms. High stress regions occur where the cross braces/columns and pontoons join; and where the columns and box beam bottom plates join. Consequently, fatigue analysis focuses those areas. The stress transfer function (STF) is obtained using dynamic finite element methods (FEMs) in the frequency domain [11,12]. Considering the complex welded joints under wave induced loads, stress intensity factor (SIF) will be collected by finite element calculation in sub-models with semi-elliptical cracks, rather than recommended empirical formulas [13,14].

A reasonable method to generate random loading spectrum [15] from short term sea conditions and the STF is employed to expand the crack iteratively. With respect to the fatigue crack propagation (FCP) model, the unique crack growth rate curve method proposed by Huang [10] considered the effect of the threshold stress intensity factor, ΔK_{th}, and the ratio of minimum to maximum SIF or ratio of minimum to maximum applied stress (R-ratios), and provides a concise model for crack growth under different R-ratios for welded joints.

The fundamental theory has been developed by previous research but the problem of the spectral-based methods in crack growth prediction for VLFSs is to define a suitable relationship between wave STF, SIF, and the FCP model. The ANSYS parametric design language (APDL) and sub-model method is adopted to allow simple application of multiple ANSYS data processes. Yan [16] described a fatigue life prediction model based on design wave method, which was a combination of fatigue loading spectrum generation, SIF calculation, and the unique curve FCP model. However, the spectral-based method proposed here will provide better accuracy because of wider coverage of wave conditions. Fig. 1 shows a flowchart of fatigue assessment.

Section 2 discusses global structural response analysis for VLFS. Section 3 introduces the basis for SIF, and develops the particular case for surface cracking at the weld toe. Section 4 develops empirical SIF formulas, which are compared to previous research outcomes in Section 5. Section 6 develops the fatigue loading spectrum, which is applied to crack propagation in Section 7. Finally, the outcomes and conclusions are presented in Section 8.

2. Global structural response

2.1. VLFS parameters

The objective model employed here is a single VLFS module in coastal waters of China. It consists of a box shaped upper hull, columns, pontoons and braces, etc. The upper hull is connected with pontoons and supported by 10 columns, as shown in Fig. 2, and the principle dimensions are listed in Table 1. High tensile structural steel, such as AH 36 or DH 36, is assumed, with parameters as shown in Table 2.

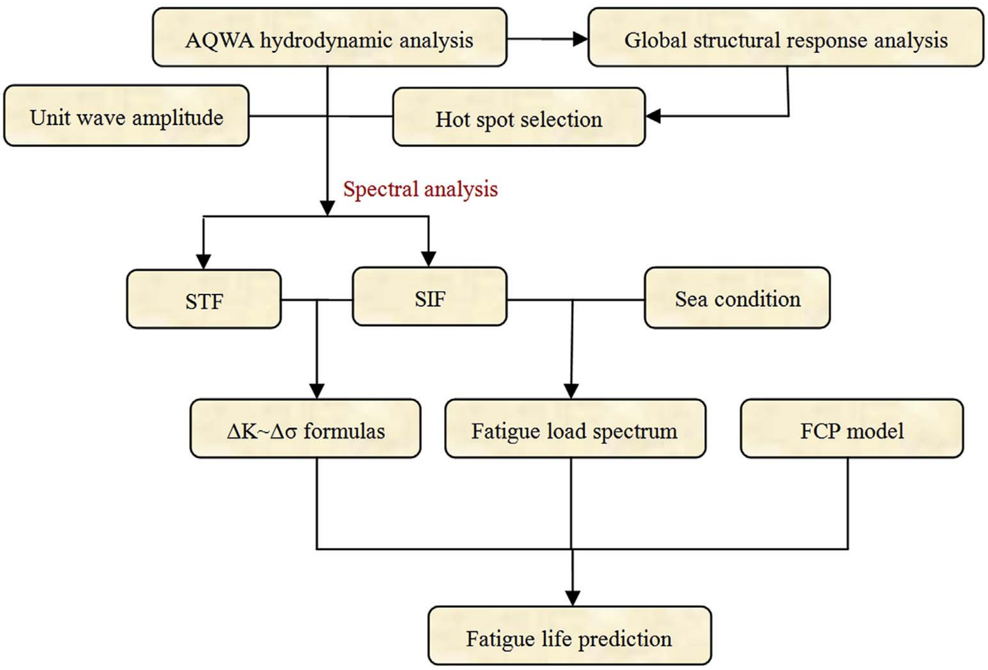

Fig. 1. Flowchart of the fatigue assessment.