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Numerical study on fatigue crack growth at a web-stiffener of ship structural details by an objected-oriented approach in conjunction with ABAQUS

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ABSTRACT

It is necessary to manage the fatigue crack growth (FCG) once those cracks are detected during in-service inspections. This is particular critical as high strength steels are being used increasingly in ship and offshore structures. In this paper, a simulation program (FCG-System) is developed utilizing the commercial software ABAQUS with its object-oriented programming interface to simulate the fatigue crack path and to compute the corresponding fatigue life. In order to apply FCG-System in large-scale marine structures, the substructure modeling technique is integrated in the system under the consideration of structural details and load shedding during crack growth. Based on the nodal forces and nodal displacements obtained from finite element analysis, a formula for shell elements to compute stress intensity factors is proposed in the view of virtual crack closure technique. Neither special singular elements nor the collapsed element technique is used at the crack tip. The established FCG-System cannot only treat problems with a single crack, but also handle problems with multiple cracks in case of simultaneous but uneven growth. The accuracy and the robustness of FCG-System are demonstrated by two illustrative examples. No stability and convergence difficulties have been encountered in these cases and meanwhile, insensitivity

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to the mesh size is confirmed. Therefore, the FCG-System developed by authors could be an efficient tool to perform fatigue crack growth analysis on marine structures.

1. Introduction

It is well known that ship and offshore structures may be exposed to fatigue failure due to dynamic loads induced by waves and slowly varying loads due to loading and unloading operations. There exist two major ways to handle fatigue problems. One of them is the S–N approach while the other is fatigue crack growth (FCG) approach. Basically, the former one is based on the analysis of stress while the later is based on the theory of fracture mechanics. The S–N approach has been developed quite well and it can be used to predict where and when the fatigue crack will initiate in a perfect structure [1–5]. However, it cannot answer questions regarding the crack growth rate and path after a crack is formed.

On the other hand, a large tanker may have hundreds or even thousands of fatigue cracks discovered during inspections. For a particular example of tanker Castor, fatigue cracks could grow to be as large as 24 m across the deck [6]. If fatigue crack growth is not well managed, it may finally either cause the loss of oil/water tightness of critical compartments to degrade serviceability, or lead to catastrophic crack size to break down the structures. To avoid those events, it is necessary to establish the inspection process and inspection planning in frame of fatigue crack growth with the economic and safety targets [7–10]. Therefore, analysis on fatigue crack growth in maritime structures has attracted much more attentions recently.

Basically, fatigue crack growth analysis involves predicting the fatigue crack path and assessing the remaining service life. However, this is quite a challenge in structure mechanics and therefore, very limited results have been reported with respect to marine structures [6,9–14]. Sumi et al. developed a numerical simulation system (CP-System) which could predict the crack path and the corresponding remaining life for fatigue crack growth in a welded 3-D plate structure [11–14]. In their simulation system, the crack growth domain is treated as a two-dimensional in-plane problem. Fatigue crack paths and the remaining lives in structural details of transverse girder of a ship structure were investigated. The software SAPHIRS has been developed by three French companies [9]. A line spring method coupled with a fitted structural stiffness condensation was used to calculate the stress intensity factors so as to determine the remaining lives. However, it requires knowing the crack path a priori. Jang et al. proposed several formulas to predict fatigue crack [10]. Thorough comparisons were made on data from existing formulas by others and data from experiments by themselves. The proposed formulas can be applied to perform fatigue crack growth analysis on the weld joint between a flat bar stiffener on a transverse web frame and flange of a longitudinal stiffener on bottom plate.

In this paper, a fatigue crack growth analysis system, named after FCG-System, is established through ABAQUS Scripting Interface (ASI), which is an objected-oriented programming (OOP) using Python language. It can simulate fatigue crack growth with arbitrary path in space under mix-mode loading. Under the idea of virtual crack closure technique (VCCT), a formula is proposed to compute stress intensity factors (SIFs) for shell elements based on nodal forces and nodal displacements. Several illustrative examples, both with a single crack and multiple cracks, have shown that the developed system is accurate and robust to simulate fatigue crack growth. To our experiences, the developed FCG-System is relatively easy to practice, insensitive to mesh size and computationally efficient which makes the system is particularly powerful to handle problems of multiple cracks growing in a simultaneous but uneven manner. Therefore, it is a promising tool for naval engineers to perform fatigue crack growth analysis on marine structures.

2. Framework of FCG-System

The framework of implementation of FCG-System is shown in Fig. 1. The system consists of four subsystems (FCGanalysis, FCGgeneratemodel, FCGcrackgrowth and FCGdataprocessing) which are implemented by ABAQUS Scripting Interface using Python language [15–17]. Each sub-system is described briefly as following.