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Analysis of Three-dimensional Surface Cracks in a Welded Joint Structure Using the Shell-Solid Mixed Method

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We present a new approach to calculate stress intensity factors of three-dimensional surface cracks in welded joints of a ship structure. We analyze problems involving very different length scales, using a shell-solid mixed finite element model. In this technique, the shell element model is used on the whole ship structure, and the solid element model is adopted for the part of the welded joint with a three-dimensional surface crack. The solid model is constituted of the quadrilateral tetrahedral elements. The shell model and the solid model are connected using the semi-auto RBE3 connecting technique, which enhances the tractability of the shell-solid mixed modeling. The Virtual Crack Closure-Integral Method for the tetrahedral finite element method is used to calculate the SIFs of the surface crack. In this paper, the numerical approach and the application are demonstrated.

INTRODUCTION

There are many plates and beams in a ship structure. The structural members are joined by welding. Surface cracks may initiate at the weld toe in the welded joints and propagate under cyclic/complex loading. It is important to know the behavior of the crack propagation. In this study, we present an effective and accurate mechanical evaluation approach to the surface crack problem in the structural members of a ship. Finite element analyses (FEA) are widely used in structural analyses of ships. Shell finite elements are used to model the ship structures. It is difficult to take into account three-dimensional surface cracks in the shell element model. It is known that solid elements are needed to solve three-dimensional crack problems. Many degrees-of-freedom are needed to analyze the cracks in very large and very thin ship structural members. One of the computational techniques to solve the problem involving varying scale is the global-local finite element method (Mote, 1971). The zooming method is also used as the global-local analysis (Hirai, Wang and Pilkey, 1984). In the shell-solid zooming method, the shell model is used as the global model and the solid model is used as the local model. The global model deformation is applied to the local model as the force or the displacement boundary condition. However, complicated tasks are needed to enforce the boundary condition on the three-dimensional complex-shaped structure, and the zooming analyses must be performed twice or more when the local model is much smaller than the global model. There are some difficulties in adopting the shell-solid zooming method for practical application when analyzing ship structures. In recent years, some researchers have proposed techniques to improve the tractability of shell-solid methods, and these techniques are used in some engineering applications (Nakasumi et al., 2001a, 2001b; Osawa, Hashimoto et al., 2007; Osawa, Sawamura et al., 2008; Tanaka et al., 2010).

We present a highly accurate and efficient approach to calculate the stress intensity factors (SIFs) for three-dimensional surface cracks in ship structural members. A semi-auto connecting technique using Rigid Body Element 3 (RBE3) in MSC.Nastran is adopted to create the shell-solid mixed model. The whole structure of the ship is modeled by triangular or quadratic-shaped shell elements, and the local structure with the weld and the surface crack is modeled by the tetrahedral solid elements. The geometry of the local structure is created using commercial 3D-CAD software and automatic tetrahedral mesh generation is carried out. Using the 3D-CAD and automatic mesh generation software enhances the efficiency of the FEA for the three-dimensional complex-shaped structure. The shell and solid models are combined with the semi-auto RBE3 connecting technique to perform the analysis with high accuracy and efficiency. Related research presents a technique using finite shell element to solid zooming with ABAQUS software and the fracture mechanics analysis have been adopted in Lebaillif et al. (2005) and Lebaillif and Recho (2007).

We calculate the SIFs using the Virtual Crack Closure-Integral Method (VCCM) for quadratic tetrahedral finite elements (Okada, Kawai and Araki, 2008). In the VCCM, the SIFs are computed by using the nodal forces and the opening displacements of the FEA solutions. When the tetrahedral finite elements are used, three-dimensional crack propagation analysis is relatively easy, because automatic tetrahedral mesh generation software is available. An automated crack propagation analysis system has been proposed using tetrahedral finite elements and the VCCM (Tokuda et al., 2010). Although commercial FEA software such as ABAQUS and MSC.Marc can calculate the SIFs for the three-dimensional surface crack, it is difficult to model the three-dimensional surface crack in the complex-shaped structure, because hexahedral elements are needed in the crack modeling and the SIFs calculation. Most fracture mechanics analyses have been done manually with

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