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Optimization of Ship Structure Based on Zooming Finite Element Analysis with Sensitivities

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ABSTRACT

This paper studies the design optimization process of ship structure with a large opening with the zooming finite element method for stress analysis so as to reduce computational effort. In order to handle the effects of the design variables existing in any part of the structure on the zooming region, the sensitivities of the design variables are utilized for computing the boundary conditions for zooming finite element analysis. The use of a different mesh pattern in zooming analysis from global analysis is possible; the effect of mesh refinement on the optimization process is also examined. It is shown that the accuracy of the stress analysis is improved, resulting in a more rational optimization of ship structure. Not only displacement but also stress boundary conditions are applied, and a comparison is made to describe their effects.

INTRODUCTION

The optimum design of a cargo ship for carrying steel materials is considered. The ship, intended for cargo operation under any weather condition, is designed to have a roof and a large cargo opening on the side hull. However, there are some difficulties in structural design due to the large opening, and appropriate modification is required. Since the shape of this kind of cargo ship is unique, the size of stiffeners and the thickness of plates are far from those used in other cargo ships for which many data and experiences are available. In order to obtain the best design of cargo ship structure under the given conditions, one of the optimization techniques, Genetic Algorithm (GA) (Kitamura, 2000a, 2000b, 2001), is introduced here.

Finite element analysis is a useful tool for analyzing stresses on many kinds of structures. However, in structural optimization problems in which numerical analyses for a large number of design plans are needed, simple and/or easy calculation methods are customarily used in order to avoid a great deal of computational time. Especially in the optimization process of large structures such as ships, it is almost impossible to repeat finite element analysis for a whole structure. Hence some modifications are studied in this paper in order to utilize finite element analysis during structural optimization processes.

Zooming finite element analysis (e.g. Jara, 1988) is widely used if a stress concentration part or a significant part exists in structures. It is then better to use a zooming model for stress analysis via FEM because of its computational resources, especially for the optimization process, in which thousands of structural analyses are required. However, there are design variables not only inside but also outside the zooming region. The effects of the design variables existing outside the zooming region cannot be taken into account for zooming stress analysis directly. So, if zooming finite element analysis is used for structural design optimization problems, some consideration is necessary for this kind of design variables. Because the effects of the design variables existing away from the zooming region should be implemented on the boundary conditions applied on the zooming boundary, some attention is paid in the sensitivity analysis for evaluating boundary conditions of the zooming FEM model in this optimization problem.

STRUCTURE ANALYSIS WITH SENSITIVITIES

A function u whose variables of x_i is under consideration. The Taylor formula with the 1st and 2nd order derivatives is given as follows:

$$u(x_1+\delta x_1,\dots,x_n+\delta x_n)=u(x_1,\dots,x_n)+\sum_{i=1}^{n}\frac{\partial u(x_1,\dots,x_n)}{\partial x_i}\delta x_i + \frac{1}{2}\sum_{i=1}^{n}\sum_{j=1}^{n}\frac{\partial^2 u(x_1,\dots,x_n)}{\partial x_i \partial x_j}\delta x_i \delta x_j \tag{1}$$

x_i: design variables $(i=1,2,\dots,n)$, $u(x_i)$: solution with design variables of initial values, $u(x_i+\delta x_i)$: solution with design variables changed by δx_i.

In the above, the 1st and 2nd order derivatives can be computed by the following equations:

$$\frac{\partial u(x_1,\dots,x_n)}{\partial x_i}=\frac{1}{2\bar{\delta}x_i}\{u(x_1,\dots,x_i+\bar{\delta}x_i,\dots,x_n) - u(x_1,\dots,x_i-\bar{\delta}x_i,\dots,x_n)\} \tag{2}$$

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KEY WORDS: Finite element method, ship structural design, optimization problems, genetic algorithm, zooming analysis, sensitivity analysis.