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Development of Pareto strategy multi-objective function method for the optimum design of ship structures

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Abstract

It is necessary to develop an efficient optimization technique to perform optimum designs which have given design spaces, discrete design values and several design goals. As optimization techniques, direct search method and stochastic search method are widely used in designing of ship structures. The merit of the direct search method is to search the optimum points rapidly by considering the search direction, step size and convergence limit. And the merit of the stochastic search method is to obtain the global optimum points well by spreading points randomly entire the design spaces. In this paper, Pareto Strategy (PS) multi-objective function method is developed by considering the search direction based on Pareto optimal points, the step size, the convergence limit and the random number generation. The success points between just before and current Pareto optimal points are considered. PS method can also apply to the single objective function problems, and can consider the discrete design variables such as plate thickness, longitudinal space, web height and web space. The optimum design results are compared with existing Random Search (RS) multi-objective function method and Evolutionary Strategy (ES) multi-objective function method by performing the optimum designs of double bottom structure and double hull tanker which have discrete design values. Its superiority and effectiveness are shown by comparing the optimum results with those of RS method and ES method.

Keywords: Multi-objective function method; Direct search method; Stochastic search method; Evolutionary strategy; Pareto optimal; Pareto strategy; Optimum design; Ship structures

1. Introduction

Generally ship structures are consisted of plate and stiffener members, which have lower and upper limit with discrete values. Various objects such as minimum weight, minimum cost and maximum reliability are required to perform the good design. Therefore, it is necessary to develop a new optimum technique for the consideration of the discrete design variables and multi-objective functions.

Until now, various Gradient methods and Search methods have been developed, and applied to the actual design of ships (Moe and Lund, 1968; Yim and Yang, 1988). In the viewpoint of structural design of ships, the Gradient method can search the optimum points rapidly, but it is difficult to differentiate the object functions with discrete design variables. The Search method such as direct search method and stochastic search method is widely used for the optimum design of ship structures. The direct search method such as Hooke & Jeeves method (Hooke and Jeeves, 1961) and Nelder & Mead method (Nelder and Mead, 1965) is widely used for the optimum design of ship structures with single objective function (Jang and Na, 2000), but it is difficult to find the global optimum point.

For several decades, the stochastic search method such as Genetic Algorithm (Goldberg, 1989; Kim, 1994; Yang et al., 1994; Nobukawa and Zhou, 1996) and Evolutionary Strategy

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(Schwefel, 1981) method was widely used for the optimum design of ship structures with single objective function. Recently, the stochastic search method such as Genetic Algorithm (Mori et al., 2014) and Evolutionary Strategy (Knowles and Corne, 1999; Shin et al., 2002, 2006; Sekulski, 2014) method is widely used for the optimum design of ship structures with multi-objective functions. It is known that Evolutionary Strategy method requires a little search time compared with Genetic Algorithm method (Ruy and Yang, 1994; Shin, 2000). Sometimes these methods are not able to search the global optimum points well for the discrete design variables such as number of longitudinal and number of web frame. These variables are very sensitive to the objective functions and the constraint functions.

This phenomenon was found in our previous papers (Karr et al., 2002; Na and Karr, 2002) regarding the optimum structural design of ships, and needed to develop a new algorithm. A Random Search (RS) method (Na, 2005) was developed by combining the merits of direct search method and stochastic search method, and it was applied to the actual design of ship structures (Na et al, 2005). The merits of direct search method are the search direction based on the Pareto optimal (Pareto, 1896), the step size by using lower & upper limit values, the convergence limit related with step size. And the merit of the stochastic search method is to obtain the global optimum points well by spreading points randomly entire the design spaces. However, this method has still a little low probability to obtain the global optimum points.

In this study, Pareto Strategy (PS) method for the multi-objective function and single objective function will be developed to improve the probability to find the global optimum points by considering the success points between just before and current Pareto optimal points based on the existing Random Search method. Several applications will be performed for the design of ship structures such as double bottom structure and double hull tanker. Its superiority and effectiveness will be shown by comparing the optimum results with those of RS method and Evolutionary Strategy (ES) method. Also, the optimum results of multi-objective function method will be compared with those of single objective function method.

In future, PS method will be combined with the efficient stiffness method developed by Authors (Na and Karr, 2013). And then more practical optimum designs of ship structures will be performed by consideration of the Harmonized Common Structural Rules (Korean Register of Shipping, 2015) for the longitudinal members and the efficient stiffness method for the transverse members.

2. Algorithm of Pareto strategy method (PS)

An algorithm of Pareto Strategy (PS) method for multi-objective function and single objective function was developed to improve the probability to find the global optimum points by considering the success points between just before and current Pareto optimal points as follows. This method was considered the search direction based on the Pareto optimal, the step size by using lower & upper limit values, the convergence limit related with step size, and the random number generator.

(1) Generate initial points randomly throughout the design space, and make discrete design values from continuous ones. The discrete design values are the interval to make real design value (for example, plate thickness is 0.5 mm, longitudinal space is 10 mm).

$$\begin{aligned} (X_j)_i &= (X_j)_{\min} + r_1 * \{(X_j)_{\max} - (X_j)_{\min}\} \\ (\overline{X_j})_i &= discrete((X_j)_i) \\ r_1 &= RAN() : 0.0 < r_1 < 1.0 \end{aligned} \tag{1}$$

where, $(X_j)_{min}$: minimum value of each design variable

$(X_j)_{max}$: maximum value of each design variable
i: current number of design point (1 ≤ i ≤ NPI)
j: current number of design variable (1 ≤ j ≤ N)
NPI: number of initial points
N: number of design variables
RAN: random number generator

(2) Calculate the object functions (F), constraints (G) and penalty functions (P), and select good points which satisfy the constraints.

$$\begin{aligned} (P_1)_i &= F_1((X_j)_i) + \lambda_1 \sum_{ic=1}^{NC} \max\{-G(ic), 0\} \\ (P_2)_i &= F_2((X_j)_i) + \lambda_2 \sum_{ic=1}^{NC} \max\{-G(ic), 0\} \end{aligned} \tag{2}$$

where, λ_1, λ_2: Lagrange multiplier (adopted very big constant, 1×10^{20})

ic: current number of constraint
NC: number of constraints

(3) Generate new points based on the good points (or parent points as shown in Fig. 2), and make discrete design values. As shown in Fig. 1, a new point (solid circle) is generated from the good point (X mark). So, the new point can be generated in entire design region.

$$\begin{aligned} (X_j)_i &= (X_j)_m + \delta * r_2 * \{(X_j)_{\max} - (X_j)_{\min}\} \\ (\overline{X_j})_i &= discrete((X_j)_i) \\ \mathrm{m} &= \mathrm{int}(\mathrm{RAN}() * \mathrm{NPAR} + 1) \\ \mathrm{r}_2 &= 2.0 * \mathrm{RAN}() - 1.0 : -1.0 < \mathrm{r}_2 < 1.0 \end{aligned} \tag{3}$$

where, δ: search step size ($0.0 < \delta < 1.0$)

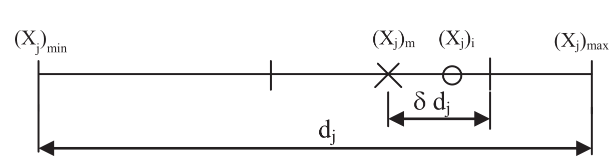

Fig. 1. Generate a new point.

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