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Study on Optimization for Large Structures using Hybrid GA

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1. Abstract
A lot of stiffeners are attached large structures. The optimization of the structure with design valuable of number and position of stiffeners is difficult. Because there are problems with creating FEM model and optimization method. When the number of stiffener is changed, FEM model is recreated. As a result, the time for optimization is increase. Therefore, a calculation method for evaluation of the structure's strength without recreating FEM models by the change of the design is proposed. The optimization time is curtailed using this calculation method.
Also, this optimization is combinational optimization problem. Therefore, the genetic algorithm is used. However, when all design variable is expressed as strings, strings length becomes long. As a result, the convergence deteriorate and the calculation amount is increased. In order to solve this problem, the Hybrid GA which combined the genetic algorithm with the other optimization method is proposed. The structural optimization is performed using two proposed method.
2. Keywords: FEM, structural optimization, hybrid GA

3. Introduction
The optimization of large structures is important for the design. The optimization of the structure with design variable of the plate thickness and the shape of stiffener is popular study filed and many reported. A ship is one of large structures. A ship has a lot of number of stiffeners. As a result, in order to obtain the better optimal solution, the optimization of the structure with design valuable of number and position of stiffeners is required. However, there is a problem as creation time of FEM models.[1][2] The FEM model has to be defined nodes at the position of stiffeners as a characteristic of FEM. When new nodes are added, the adjustability of mesh is lost. It is necessary to recreate the FEM model, in order to maintain the adjustability of mesh. However, the optimization of the structure has to examine much number of propositions for design. Creating FEM models is required a long time. As a result, it is too difficult to create FEM models of all propositions for design. Therefore, a calculation method for evaluation of the structure's strength without recreating FEM models by the change of the design is proposed.
This optimization is combinational optimization problem. Therefore, the genetic algorithm is used. However, when all design variable is expressed as strings, strings length becomes long. When the optimization is performed using this strings, the convergence becomes aggravation. As a result, it is difficult to get the optimal solution. In order to solve this problem, a study about the hybrid GA is advanced. In this study, Hybrid GA which combined the genetic algorithm with the other optimization method is applied.
The structural optimization for large structures is performed using these two method in this study.

4. Research target
The research target is shown in Fig 1. The stiffeners are allocated in the plate. In this study, the model is optimized. The design valuables are plate thickness and the number of stiffeners, the position of stiffeners, the shape of stiffeners.

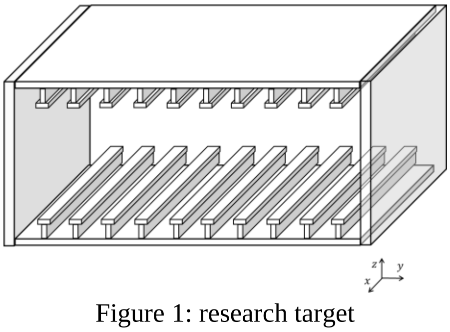

Figure 1: research target

4. Calculation method for FEM

The method of changing stiffness and degree of freedom is explained by this section.
The rigid matrix of target FEM model is divided into α and β. α is region of unchanged structure. β is region of changed structure. Next, the region of adding nodes are added. This region is γ. When stiffness equation is divided into three of region, the stiffness equation is expressed by Eq.(1). [3]

$$\begin{bmatrix} \boldsymbol{K}_{\alpha\alpha} & \boldsymbol{K}_{\alpha\beta} & 0 \\ \boldsymbol{K}_{\beta\alpha} & \boldsymbol{K}_{\beta\beta} + \Delta\boldsymbol{K}_{\beta\beta} & \Delta\boldsymbol{K}_{\beta\gamma} \\ 0 & \Delta\boldsymbol{K}_{\gamma\beta} & \Delta\boldsymbol{K}_{\gamma\gamma} \end{bmatrix} \begin{bmatrix} \boldsymbol{x}'_{\alpha} \\ \boldsymbol{x}'_{\beta} \\ \boldsymbol{x}'_{\gamma} \end{bmatrix} = \begin{bmatrix} \boldsymbol{f}_{\alpha} \\ \boldsymbol{f}_{\beta} \\ \boldsymbol{f}_{\gamma} \end{bmatrix} \tag{1}$$

x'_{α} and x'_{β}, x'_{γ} are expressd by the displacement of after changed sructure. f_{α} and f_{β}, f_{γ} are expressd by the load vector of after changed sructure.Also, $f_{\gamma} = 0$ because adding nodes are nothing.When Eq.(1) is solved about x'_{α} and x'_{β}, x'_{γ},it gets Eq.(2).

$$\begin{bmatrix} \boldsymbol{G}_{\alpha\alpha} & \boldsymbol{G}_{\alpha\beta} & 0 \\ \boldsymbol{G}_{\beta\alpha} & \boldsymbol{G}_{\beta\beta} & 0 \\ 0 & 0 & \boldsymbol{I} \end{bmatrix} \begin{bmatrix} \boldsymbol{f}_{\alpha} \\ \boldsymbol{f}_{\beta} - \Delta\boldsymbol{K}_{\beta\beta}\boldsymbol{x}'_{\beta} - \Delta\boldsymbol{K}_{\beta\gamma}\boldsymbol{x}'_{\gamma} \\ -\Delta\boldsymbol{K}_{\gamma\gamma}^{-1}\Delta\boldsymbol{K}_{\gamma\beta}x'_{\beta} \end{bmatrix} = \begin{bmatrix} \boldsymbol{x}'_{\alpha} \\ \boldsymbol{x}'_{\beta} \\ \boldsymbol{x}'_{\gamma} \end{bmatrix} \tag{2}$$

The *G* matrix of Eq.(2) is the inverse matrix of whole stiffness matrix shown in Eq.(3).

$$\begin{bmatrix} \boldsymbol{G}_{\alpha\alpha} & \boldsymbol{G}_{\alpha\beta} \\ \boldsymbol{G}_{\beta\alpha} & \boldsymbol{G}_{\beta\beta} \end{bmatrix} = \begin{bmatrix} \boldsymbol{K}_{\alpha\alpha} & \boldsymbol{K}_{\alpha\beta} \\ \boldsymbol{K}_{\beta\alpha} & \boldsymbol{K}_{\beta\beta} \end{bmatrix}^{-1} \tag{3}$$

When Eq.(2) is simplified, x'_{β} and x'_{γ} are expressed by Eq.(4).

$$\begin{bmatrix} \boldsymbol{x}'_{\beta} \\ \boldsymbol{x}'_{\gamma} \end{bmatrix} = \begin{bmatrix} \boldsymbol{G}_{\beta\alpha}\boldsymbol{f}_{\alpha} + \boldsymbol{G}_{\beta\beta}(\boldsymbol{f}_{\beta} - \Delta\boldsymbol{K}_{\beta\beta}\boldsymbol{x}'_{\beta} - \Delta\boldsymbol{K}_{\beta\gamma}\boldsymbol{x}'_{\gamma}) \\ \Delta\boldsymbol{K}_{\gamma\gamma}^{-1}\boldsymbol{f}_{\gamma} - \Delta\boldsymbol{K}_{\gamma\gamma}^{-1}\Delta\boldsymbol{K}_{\gamma\beta}\boldsymbol{x}'_{\beta} \end{bmatrix} \tag{4}$$

$\boldsymbol{G}_{\beta\alpha}\boldsymbol{f}_{\alpha} + \boldsymbol{G}_{\beta\beta}\boldsymbol{f}_{\beta}$ is expressed by $\boldsymbol{x}_{\beta}$. Then, substituted $\boldsymbol{G}_{\beta\alpha}\boldsymbol{f}_{\alpha} + \boldsymbol{G}_{\beta\beta}\boldsymbol{f}_{\beta}$=$\boldsymbol{x}_{\beta}$ for Eq.(4) and solved x'_{β} and x'_{γ} .As a resut, Eq.(5) is got.

$$\begin{bmatrix} \boldsymbol{x}'_{\beta} \\ \boldsymbol{x}'_{\gamma} \end{bmatrix} = \left[\begin{bmatrix} \boldsymbol{I} & 0 \\ 0 & 0 \end{bmatrix} + \begin{bmatrix} \boldsymbol{G}_{\beta\beta} & 0 \\ 0 & \boldsymbol{I} \end{bmatrix} \begin{bmatrix} \Delta\boldsymbol{K}_{\beta\beta} & \Delta\boldsymbol{K}_{\beta\gamma} \\ \Delta\boldsymbol{K}_{\gamma\beta} & \Delta\boldsymbol{K}_{\gamma\gamma} \end{bmatrix} \right]^{-1} \begin{bmatrix} \boldsymbol{x}_{\beta} \\ 0 \end{bmatrix} \tag{5}$$

In order to solve displacement after adding nodes, $\boldsymbol{G}_{\beta\beta}$ and $\Delta\boldsymbol{K}, \boldsymbol{x}_{\beta}$ are requared. Also, when Eq.(2) is solved about $\boldsymbol{x}'_{\alpha}$, Eq.(6) is got.

$$\boldsymbol{x}'_{\alpha} = \boldsymbol{x}_{\alpha} - G_{\alpha\beta}\left(\Delta K_{\beta\beta}x'_{\beta} + \Delta K_{\beta\gamma}x'_{\gamma}\right) \tag{6}$$

It becomes possible to calculate the displacement after changed structures using Eq.(5) and Eq.(6). As a result, the number of stiffeners can be changed without recreating FEM model using this calculation method.

4. Hybrid GA

The hybrid GA is optimization method which combined GA with other optimization method. In this section, the design variables treated by GA and the other optimization method are explained. The flow of hybrid GA is sown in Fig. 2.

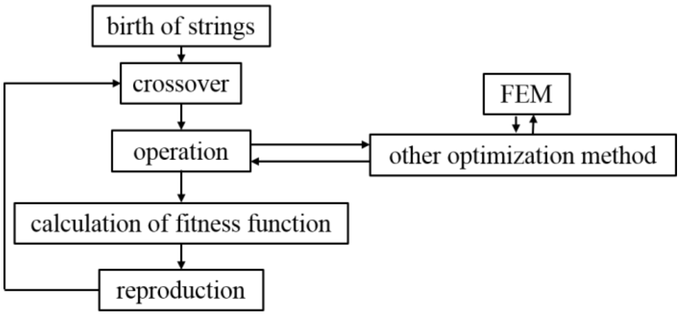

Figure 2: flow of hybrid GA

4.1 genetic algorithm

The design valuables are plate thickness and the number of stiffeners, the position of stiffeners, the shape of stiffeners. The shape of stiffeners is chosen from select list. Then, discrete variable are the shape and number of stiffeners. The optimization with discrete variable can be performed using GA. Therefore, these two design variables are treated by GA. In order to perform optimization by GA, the design variables was expressed by strings is shown in Fig 3.

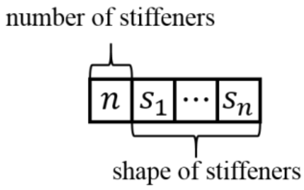

Figure 3: strings

4.2 other optimization method

The plate thickness and the number of stiffeners are near the continuous variable. Then, the optimization with these two design variables is difficult to perform by GA. Therefore, the other optimization method is proposed. First, updating method for design variables is explained. In plate bending theory, the bending stress of plate is expressed by Eq.(7).

$$\sigma = \beta \frac{pl^2}{t^2} \tag{7}$$

σ : bending stress
p : uniformly varying load
l : plate length
t : palte thickness
β : correction coefficient with aspect ratio

When step a is the present design variable, t_a is expressed by Eq.(8)

$$t_a = \beta \frac{pl_a}{\sqrt{\sigma_a}} \tag{8}$$

If σ_a agrees with the constraint condition in step a+1, t_a is expressed by Eq.(9)

$$t_{a+1} = \beta \frac{pl_{a+1}}{\sqrt{\sigma_c}} \tag{9}$$

σ_c : constraint condition

Eq.(10) is got from Eq.(8) and Eq.(9).

$$t_{a+1} = \frac{t_a l_{a+1}}{l_a} \frac{\sqrt{\sigma_a}}{\sqrt{\sigma_c}} \tag{10}$$

When span is changed, plate thickness is decided satisfactory to the constraint condition by Eq.(10).Also, when l_{a+1}=l_a, Eq.(11) is got.

$$t_{a+1} = t_a \frac{\sqrt{\sigma_a}}{\sqrt{\sigma_c}} \tag{11}$$

In this method, span and plate thickness are updated by Eq.(10) and Eq.(11).

This optimization method of process is shown in Fig. 4.

(1) The plate thickness is changed by Eq.(11).
(2) Each span is extended unit length. The weight is calculated and the efficient vector of span is calculated.
(3) When span is changed using calculated vector, plate thickness is changed by Eq.(10).
(4) The weight after changed span and thickness is calculated. So, the weight is judged whether minimum weight or not.
(5) The stress is analyzed using FEM.

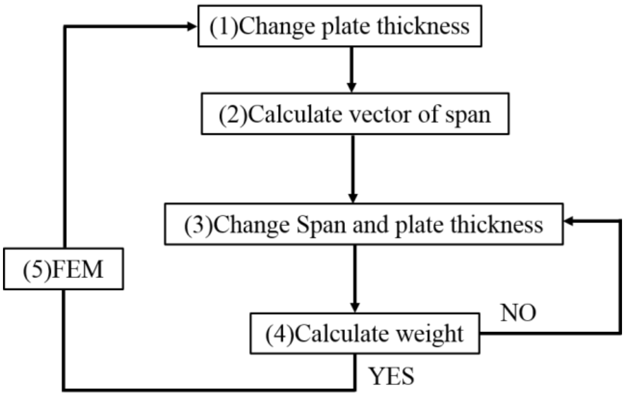

Figure 4: flow of optimization method

4.3 example problem

In this section, the hybrid GA is examined. The optimization target is shown in Fig.5. When optimization is performed using FEM, the optimization time becomes long. Therefore, the testing is performed without FEM. Eq.(12) is used instead of FEM. When span is extended, the rigid of stiffener is down and thickness is thinned, stress is upped.

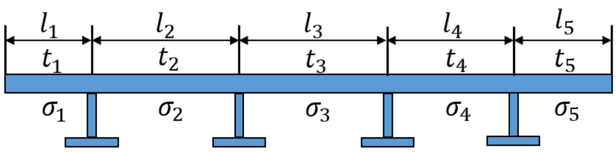

Figure 5: optimization target for example problem

$$\sigma_i = l_i + \frac{1}{t_i} + \frac{1}{I_i} \tag{12}$$

σ_i : ith stress
l_i : ith span
t_i : ith thickness
I_i : ith inertia of stiffener

The object function is expressed by Eq(13).The constraint condition is expressed by Eq(14).In this example problem, σ_c is 35. The augmented object functions using Eq.(13) and Eq(14) is expressed by Eq.(15).The design variables is the span and plate thickness.

$$f(X) = weight \tag{13}$$

$$g(X) = \sum_{i=1}^{n} \max[0, \frac{(\sigma_i - \sigma_c)}{\sigma_c}] \quad (14)$$

σ_i : stress of constraint condition

$$F(X) = f(X) + rg(X) \quad (15)$$

The result of optimization is shown in Fig.6. The stress of constraint condition to be satisfied. Stiffeners are allocated at regular intervals. As a result, attached stiffeners properly by this method are confirmed.

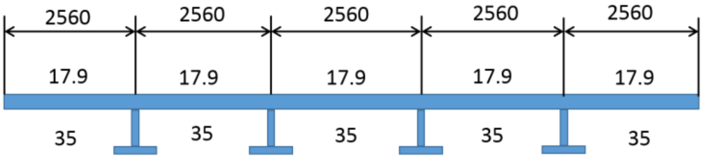

Figure 6: result of optimization

5. Structural optimization

In this section, The optimization is peformed by eq (10).The FEM model for optimization is shown in Fig.7. The stiffner is allocated in the x-direction. The region of optimization is top plate.The object fanction is weight. The weight is minimized. The constraint condition is Eq(14).σ_c is 5. σ_i is the max stress of between stiffeners. The design variables is the span and plate thickness. The load condition is shown in Fig.8.

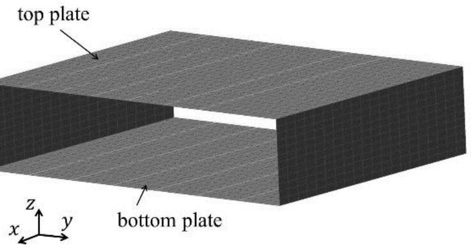

Figure 7: FEM model for optimization

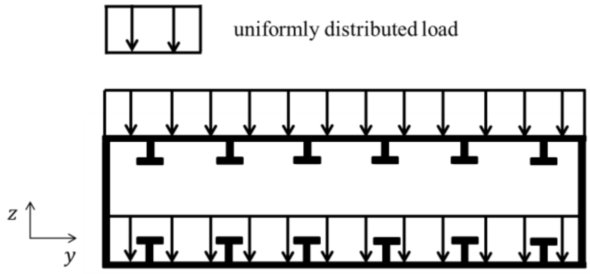

Figure 8: load condition

The result of optimization is shown in Fig.9. The stress of theses plates are excepted from constraint condition. Stiffeners are allocated at bilateral symmetry. As a result, attached stiffeners properly by this method are confirmed.

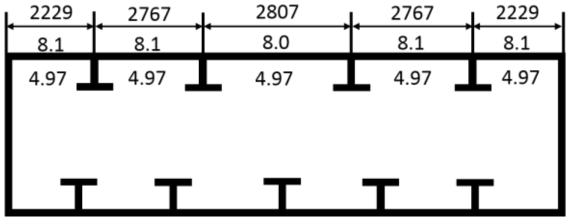

Figure 9: result of optimization

6. Conclusion

In this study, optimization of the ship structures with design valuable of the number and position of stiffeners is performed. The following two methods are proposed for optimization of the ship structures.

1. The calculation method for evaluation of the strength structures without recreating FEM models is proposed.

2. The hybrid GA which combined GA with proposed optimization method is proposed.

When optimization is performed using the three above mentioned method, stiffeners are allocated at proper positions and optimal solution can be got. As a result, the efficacy of proposed methods is confirmed.

7. References

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