10th World Congress on Structural and Multidisciplinary Optimization
May 19 -24, 2013, Orlando, Florida, USA

# A Study on Optimizing the Structures which Set the Number of Member Subjects and Plate Thickness to the Design Variable

**Ryota Nonami[1], Mitsuru Kitamura[2], Akihiro Takezawa[3], Shinichi Hirakawa[4]**

[1] Hiroshima University, Graduate School of Engineering, Department of Transportation and Environmental Systems

[2] Professor, Hiroshima University, Faculty of Engineering, Division of Mechanical Systems and Applied Mechanics

[3] Associate Professor, Hiroshima University, Faculty of Engineering, Division of Mechanical Systems and Applied Mechanics

[4] Japan Marine United Corporation TECHNICAL RESERCH CENTER Structural Research Group

## 1. Abstract

The optimization of the ship structure with the allocation of member subjects is considered by a new calculation method in this study. FEM analysis is required for strength evaluation of ship structure. The FEM models need some nodes at the allocation of member subjects as a characteristic of FEM. When the number of member subjects changes the process of the optimization of the structure, number of nodes of FEM model is also changed. Therefore, in order to ensure consistency of mesh, it is necessary to remake FEM model. In order to optimize structural, it is necessary to examine the many propositions for design. However it is difficult to create and analyze the proposition for design of many numbers in restricted time. Therefore the calculation method that doesn't depend on the number of member subjects and the allocation of member subjects is developed. The value of the displacement and stress in consideration of the influence of member subjects is acquirable by this calculation method. It will not be necessary to remake FEM model and annualize a whole structure using this calculation method. The computational effort is limited to the calculation of only the structural modification region by this calculation method. Therefore the optimization of the structure is considered with the allocation of member subjects and the number of member subjects. The optimization of the structure can be performed by this calculation method. The result of the calculation using proposed calculation method corresponds with the result of FEM. The results indicate that proposed calculation method is correct.

## 2. Research background

The optimization of the ship structure is important for the design of ship. The low cost ship can be made by optimization of the ship structure. FEM is used in the evaluation of structures of ship. The optimization of the structure with design variable of the plate thickness is performed generally. However, in order to obtain the better optimal solution, the optimization of the structure with design valuable of the number of member subjects is required. There is a problem to attach new member subjects in FEM. The FEM model needs nodes at the position of member subjects as a characteristic of FEM. If adding node is performed, the adjustability of mesh is lost. In order to maintain the adjustability of mesh, it is necessary to recreate the FEM model of ship. However, the optimization of the structure examines much number of propositions for design. Creating FEM model of ship needs a long time. Also, FEM analysis needs high computing effort. Therefore, it is unreal to create and analysis FEM model of all propositions for design. For these reasons, the optimization of the structure w with design valuable of the number of member subjects is not performed generally.[1)]

## 3. Research purpose

In this study, a calculation method for evaluation of the structures in without recreating FEM models by the change of the design is constructed. It aims that the optimization of the structure uses the proposed calculation method.

It is not necessary to calculate a whole structure when design is changed thanks to this calculation method. Therefore, the optimization time can be shortened very much.

The propose method is applied into the ship optimization. The structural calculation method of ship is defined with the rule of the shipping classification society. When the structural analysis of a large ship is performed, the FEM model which extracted its three cargo holds is used. The FEM model is shown in Fig.1. This model has 22329 nodes and 44694 elements.[2)]

The name of the component of a hull is shown in Fig. 2

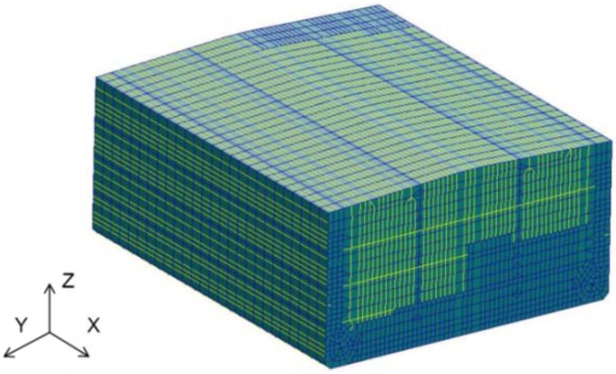


Fig1 three cargo hold mode

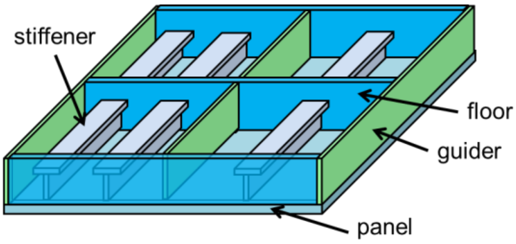


Fig 2: ship structure

**4. Calculation technique**

The based FEM model is classified into two parts α and β.The part of structure which is modified belongs to β,other parts belongs to α.In this case, the full stiffness matrix is decomposed into four-component. A stiffness equation is expressed by Eq.1.[3)]

$$\begin{bmatrix} \boldsymbol{K}_{\alpha\alpha} & \boldsymbol{K}_{\alpha\beta} \\ \boldsymbol{K}_{\beta\alpha} & \boldsymbol{K}_{\beta\beta} \end{bmatrix} \begin{bmatrix} \boldsymbol{x}_{\alpha} \\ \boldsymbol{x}_{\beta} \end{bmatrix} = \begin{bmatrix} \boldsymbol{f}_{\alpha} \\ \boldsymbol{f}_{\beta} \end{bmatrix} \tag{1}$$

$\boldsymbol{K}_{\alpha\alpha}$:stiffness matrix for no structural modification parts

$\boldsymbol{K}_{\beta\beta}$: stiffness matrix for structural modification parts

$\boldsymbol{K}_{\alpha\beta}, \boldsymbol{K}_{\beta\alpha}$: stiffness matrix for boundary parts

When the yellow element of Fig.3 is modified structure, $\boldsymbol{K}_{\beta\beta}$ are the components of stiffness matrix of red nodes. Also, $\boldsymbol{K}_{\alpha\alpha}$ are the components of stiffness matrix of yellow nodes. $\boldsymbol{K}_{\alpha\beta}$and$\boldsymbol{K}_{\beta\alpha}$ are the components of stiffness matrix of blue nodes.

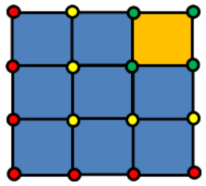

Fig 3: example model

$\Delta\boldsymbol{K}$ is newly created stiffness matrix by structural modification. $\Delta\boldsymbol{K}$ is added to structural modification position.

$$\begin{bmatrix} \boldsymbol{K}_{\alpha\alpha} & \boldsymbol{K}_{\alpha\beta} \\ \boldsymbol{K}_{\beta\alpha} & \boldsymbol{K}_{\beta\beta}+\Delta\boldsymbol{K} \end{bmatrix} \begin{bmatrix} \boldsymbol{x}'_\alpha \\ \boldsymbol{x}'_\beta \end{bmatrix} = \begin{bmatrix} \boldsymbol{f}_\alpha \\ \boldsymbol{f}_\beta \end{bmatrix} \tag{2}$$

$\boldsymbol{x}'_\alpha\ \boldsymbol{x}'_\beta$: displacement vector of after structural modification.

When Eq.2 is solved about $\boldsymbol{x}'_\alpha$ and $\boldsymbol{x}'_\beta$,it becomes Eq.3.

$$\begin{bmatrix} \boldsymbol{x}'_\alpha \\ \boldsymbol{x}'_\beta \end{bmatrix} = \begin{bmatrix} \boldsymbol{G}_{\alpha\alpha} & \boldsymbol{G}_{\alpha\beta} \\ \boldsymbol{G}_{\beta\alpha} & \boldsymbol{G}_{\beta\beta} \end{bmatrix} \begin{bmatrix} \boldsymbol{f}_\alpha \\ \boldsymbol{f}_\beta - \Delta\boldsymbol{K}x'_\beta \end{bmatrix} \tag{3}$$

The $G$ of Eq.3 is expressed by Eq.4.

$$\begin{bmatrix} \boldsymbol{G}_{\alpha\alpha} & \boldsymbol{G}_{\alpha\beta} \\ \boldsymbol{G}_{\beta\alpha} & \boldsymbol{G}_{\beta\beta} \end{bmatrix} = \begin{bmatrix} \boldsymbol{K}_{\alpha\alpha} & \boldsymbol{K}_{\alpha\beta} \\ \boldsymbol{K}_{\beta\alpha} & \boldsymbol{K}_{\beta\beta} \end{bmatrix}^{-1} \tag{4}$$

When Eq.(3) is expanded, displacement of after structural modification is expressed by Eq.(5) and Eq.(6).

$$\boldsymbol{x}'_\alpha = \boldsymbol{x}_\beta - \boldsymbol{G}_{\alpha\beta}\Delta\boldsymbol{K}\boldsymbol{x}'_\beta \tag{5}$$

$$\boldsymbol{x}'_\beta = [\boldsymbol{I} + \boldsymbol{G}_{\beta\beta}\Delta\boldsymbol{K}]^{-1}\boldsymbol{x}_\beta \tag{6}$$

The calculation effort can be reduced by this calculation method in order to solve displacement of after structural modification.

**5. Plate thickness optimization problem**

We perform the optimization of plate thickness of ships by proposed calculation method. The optimized part is shown Fig.4 and Fig.5. The enclosed red line part of Fig.4 is expanded Fig.5. The portion shown by yellow is the optimized element. The design variables are thickness of these shell elements.

The object function is weight. The constrained condition is stress. The stress of the constrained condition is less than the |315|[MPa].

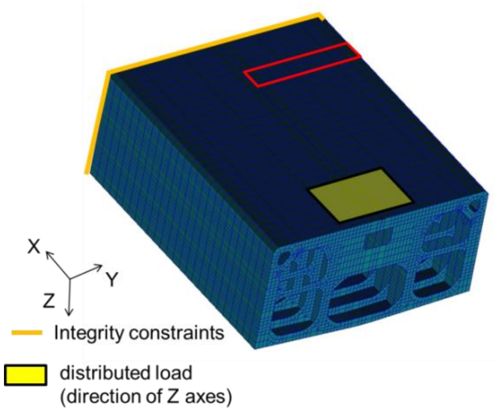


Fig 4: FEM used for the optimized model

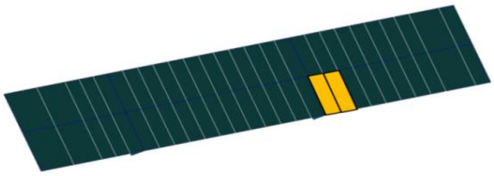

Fig 5: two elements which thicknesses are selected design variables.

The optimization results are shown in Table 1 and Fig. 6.

Table 1 initial plan and result of optimization

| | $t_1$[mm] | $t_2$[mm] | $\lvert\sigma_{1x}\rvert$[Mpa] | $\lvert\sigma_{2x}\rvert$[Mpa] |
|---|---|---|---|---|
| Initial plan | 20.5 | 20.5 | 303 | 300 |
| Optimization results | 22.2 | 13.8 | 315 | 315 |

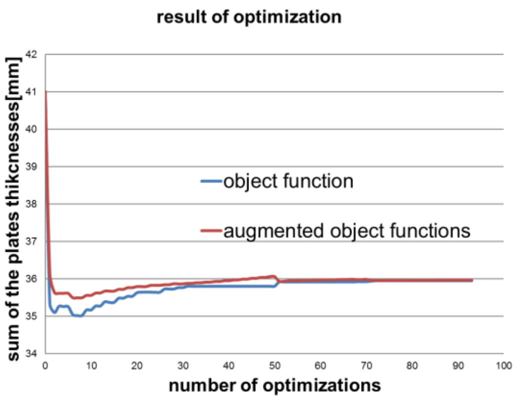


Fig 6: result of optimization

The object function is increased after decreasing. Because, whenever the generation is updated, the value of penalty coefficient is increased. Finally, the object function and the augmented object functions are in agreement. In fact, the optimization can be performed with satisfaction of the constrained condition.[6)]

In the case of traditional calculation method, the calculation amount of optimization is matrix size of the total degree of freedom of calculating. The proposed calculation amount is only two element. The calculation amount of optimization is matrix size of 36×36 of calculating. The amount of optimized calculation effort can be reduced significantly using proposed calculation method.

**6. Changing design with added nodes**

When the optimization of the structure with design valuable of the number of member subjects is preformed, new nodes are needed to create. Then, it is necessary to carry out recreating mesh. Therefore, we explain the method for adding new nodes to a FEM model.

For example, two nodes are added the FEM model shown in Fig.7.This FEM model is plane stress element.

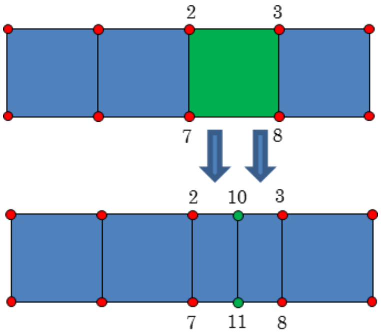


Fig 7: example model

The stiffness of two nodes are added to $G_{\beta\beta}$ is shown Fig.8.The diagonal section of stiffness of adding nodes is 1.The other section is 0.

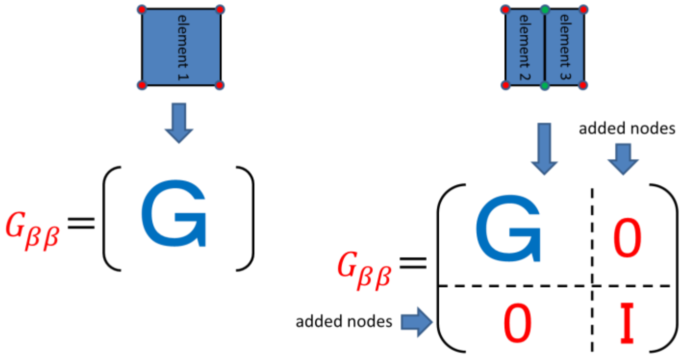


Fig 8: A way of creating $\boldsymbol{G_{\beta\beta}}$

Concrete example is shown in Fig.8.Therefore, created $G_{\beta\beta}$ is substituted for Eq.6.

$\Delta K$ is the difference between the stiffness matrix before performing structural modification and the stiffness matrix after performing structural modification. However, these two matrixes differ in size. And so, the region of the added nodes is added to the stiffness matrix before performing structural modification shown in Fig.9.

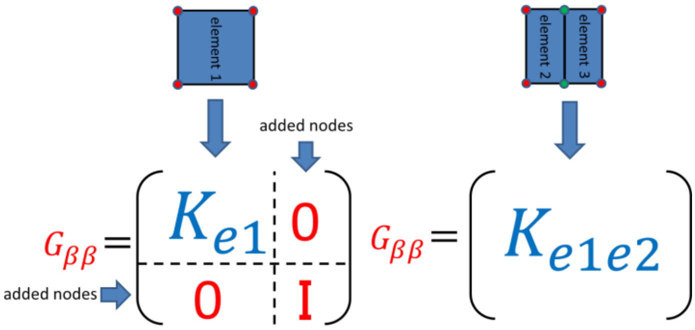


Fig 9: A way of creating $\Delta\boldsymbol{K}$

0 is substituted for displacement of the added node. As a result, size of $\boldsymbol{x}_{\beta}$ is adjusted.

$\boldsymbol{G}_{\beta\beta}, \Delta\boldsymbol{K}, \boldsymbol{x}_{\beta}$ are substituted for Eq.6. As a result, it becomes possible to calculate the displacement a after performing structural modification.

## 7. The ship structural optimization

The proposed method is applied to the ship structure. The mishap section is shown in Fig.10. The optimization region is the bottom of the ship enclosed in the red line of Fig.10.

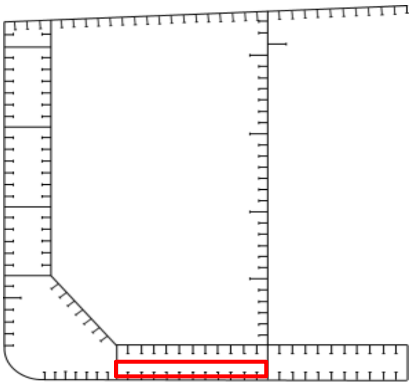

Fig 10: mishap section

The design variables are number of stiffeners and plate thickness. The object function is weight. The object function is expressed as Eq.7.

$$f(X) = xA_sL\rho + L\rho b \sum_{i=1}^{n} t_i \tag{7}$$

$x$ : number of stiffeners

$A_s$ : stiffener area[$\mathrm{mm}^2$]

$L$ : length of ship[mm]

$\rho$ : density [$t/\mathrm{mm}^3$]

$t_i$ : plate thickness[mm]

The constrained condition is max stress. The stress of the constrained condition is less than the 0.002[MPa]. The constrained condition is expressed as Eq.8.

$$g(X) = \max[0, \sigma - 0.00002] \tag{8}$$

$\sigma$ : stress[$kgf/\mathrm{mm}^2$]

The augmented object function is expressed as Eq.9.

$$fp(X) = f(X) + rg(X) \tag{9}$$

$r$ : penalty coefficient

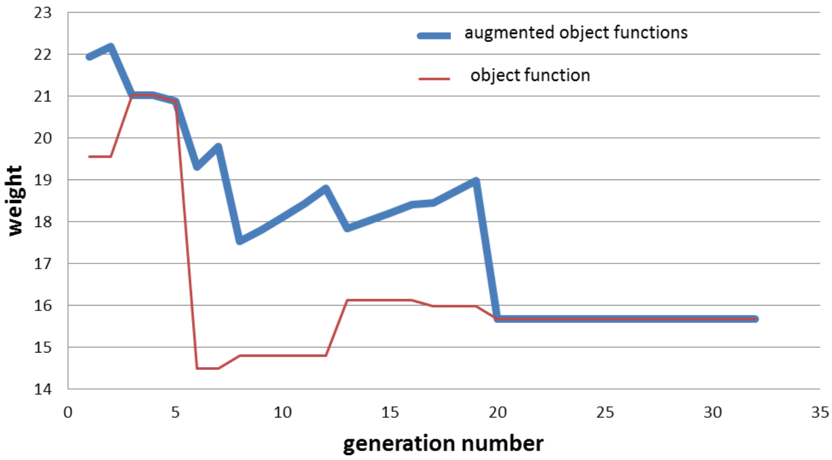


Fig 11: result of optimization

The object function is increased after decreasing in Fig.11. Because, whenever the generation is updated, the value of penalty coefficient is increased. Finally, the object function and the augmented object functions are in agreement. In fact, the optimization can be performed with satisfaction of the constrained condition. [6] The optimization of the ship structure with design valuable of the number of member subjects is able to be performed.

## 8. Conclusions

In this study, the calculation method for setting new member subjects is established without remaking a FEM model. The optimization of the number of member subjects could be performed using the proposed calculation method. The calculation effort of structural calculation can also be reduced using the proposed calculation method.

## 9. References

[1] Kitamura M Hamada K Takezawa A Uedera T: Shape Optimization System of the Bottom Structure of a Ship Incorporating Individual Mesh Sub-division and Multi-point Constraint: International Journal of Offshore and Polar Engineering,Vol. 21,No. 3,pp. 209-215,2011.

[2] Hirakawa S Kitamura Maki M: Application of Genetic Algorithm to Structural Design of 150KDWT Tankerusing PrimeShip-HULL Rule Calculation Software: International Offshore and Polar Engineering Conference,2011.

[3] Furuya K Yoshimura T Suto A Saito K :Sensitivity Analysis of FRF using Eigenvalue and Eigenvector of Component Stiffness Matrix: Dynamics and design Conference, 2004.

[4] Kitamura M Uedera T Hamada K Takezawa A: Shape and Size Optimization of the Double Bottom Structure of Bulk Carrierat the Initial Design Stage with Finite Element Analysis: International Offshore and Polar Engineering Conference,2011

[5] Abu Kassim, V. Topping : Static Reanalysis: A Review, Journal of Structural Engineering, Vol. 113, No. 5, May 1987, pp. 1029-1045.

[6] KITAMURA Mitsuru DJENDO Kaharudin NAKAMORI Takakazu YAMANAKA Motoki YAMAMOTO Motomiti : A study on Optimum Structural Design of Container Ship using Genetic Algorithms and Convergence of its Solution:THE WEST-JAPAN SOCIETY OF NAVAL ARCHITECTS bulletin (101), 185-194, 2001-03-12