

A Study on the Optimum Design of Corrugated Bulkhead for Product Carrier

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Abstract. For a product carrier, in general, longitudinal bulkhead as well as transverse bulkhead is corrugated type and the intersection part of bulkheads is utilized for a pipe trunk. Since lower and upper stools are to be connected with all of longitudinal and transverse bulkheads, they have a uniform height respectively. The purpose of this study is the development of design technique for the minimization of total weight of longitudinal and transverse bulkheads at the initial design stage. In this study, optimum design of corrugated bulkhead for product carrier was conducted by applying evolution strategy method (ESM) as an optimization method and beam elements based on generalized slope deflection method (GSDM) in structural analysis. Furthermore, the installations of pipe trunks and the interference of stool diaphragms and brackets were considered to conform to the actual ship design. The optimization results are compared with the existing 70K product carrier designed in accordance with the DNV classification requirements and showed about 3% reduction in weight.

1. Introduction

Corrugated bulkheads are used often in ships due to such advantages as easy maintenance, convenience in cargo handling, and flexibility towards expansion and contraction by thermal load. Many studies have been conducted to minimize the weight of such corrugated bulkheads and its importance is being magnified these days because of high material price.

For studies on the optimum design of corrugated bulkhead, Yum used the Hooke and Jeeves method for minimum weight design of corrugated bulkhead [1]. He focused on the optimization method rather than workability, which was sensitive to initial values, and he could obtain useful results only when the solution could be predicted to some degree. Shin and Nam conducted the optimum design of the watertight bulkhead using the evolution strategy method (ESM) which is insensitive to initial values and excellent for searching the global minimum [2]. Shin and Nam used the generalized slope deflection method (GSDM) developed by Jang and Na to conduct the optimum design of deep tank bulkhead which requires repeated structural analysis in optimization process [3, 4]. The targets of optimum design were, until now, limited to the corrugated bulkheads of bulk carriers or oil tankers whose longitudinal bulkheads are not the type of corrugated.

In this study, optimum design of corrugated bulkhead for product carrier was conducted. For the optimization method, ESM which is a global optimization method was applied. Product carrier has the corrugated type bulkheads in both longitudinal and transverse direction. The beam element model based on GSDM was applied to the structural analysis of longitudinal bulkheads (L.BHDs) and transverse bulkheads (T.BHDs) in order to conduct the minimum weight design of every corrugated bulkhead in a



product carrier. Furthermore, the installations of pipe trunks and the interference of stool diaphragms and brackets were considered to conform to the actual ship design.

2. Evolution strategy method

As optimization methods such as gradient method and direct search method are weak at global minimum search, the application of stochastic search method evolved from the direct search method is increasing. But the stochastic search method have disadvantage in searching time, researches have been conducted to overcome this problem. Lee and Kim presented a hybrid search method that combines the Hooke and Jeeves method which is a direct search method with the genetic algorithm which is a stochastic search method to reduce searching time [5]. Na developed a multi-objective function optimization method based on the Pareto optimum points which combines only the advantages of the direct search method and the stochastic search method [6]. The optimization method used in this study is the ESM which is one of the stochastic search methods. The problem of searching time can be solved by using beam elements based on GSDM in structural analysis. The results were obtained within just a few minutes.

ESM was first introduced by Rechenberg and later developed and systematized by Schwefel [7, 8]. It is similar to the genetic algorithm based on the principles of the survival of the fittest and natural selection. It is largely divided into plus strategy which is of the form $(\mu + \lambda)$ and the comma strategy which is of the form (μ, λ) . Difference between these two strategies is the participation of the parent entity in the selection step. In the plus strategy, both the parent and child entities participate in the selection, whereas in the comma strategy, only the child entity participates in the selection. In general, the plus strategy is used often, in which μ parent entities form λ child entities, and out of all of $(\mu + \lambda)$ entities, new μ parent entities with good compatibility are formed. The child entities are formed through the process of recombination and mutation.

3. Objective function

The weight of the corrugated part of the longitudinal and transverse bulkheads was set as the objective function. That is the weight of the corrugated bulkheads per one cargo hold excluding the stool structures.

In case of the deep tank bulkhead of bulk carrier, a pipe trunk is installed at the corrugated bulkhead that meets with the outer shell of the ship, but in case of product carrier, it is installed at the intersection between the longitudinal and transverse bulkheads. So the installations of pipe trunks were considered to conform to the actual ship design.

4. Design variables

The longitudinal bulkhead of the product carrier is generally installed at the ship centerline, and the heights of the upper and lower stools are identical for both longitudinal and transverse directions because they are installed in both directions.

As shown in figure 1, six design variables were set: corrugation depth of T.BHD ($X1$), corrugation flange width of T.BHD ($X7$), projection length of corrugation web of T.BHD ($X8$), corrugation depth of L.BHD ($XX1$), corrugation flange width of L.BHD ($XX7$), and projection length of corrugation web of L.BHD ($XX8$). The thickness of each plate according to these dimensions was determined by the classification rules. For the dimensions of upper and lower stools, input values by designer were used. Discrete values were used for all variables to allow application to design.

5. Constraints

The following constraints were applied. The objective functions that violate the constraints were given penalties to intentionally exclude from competition.

1) Limitation of the slope angle of the inclined plate: This angle must be maintained at 60 degrees for deep tank bulkheads of bulk carrier for which the ABS classification regulations require the calculation of transverse strength if it is smaller than 60 degrees.

2) Limitation of the corrugation depth: For the design of watertight bulkheads, 2.5 times the corrugation depth must be smaller than the bottom width of the lower stool as a condition of the IACS

UR regulation. Furthermore, the corrugation depth was set not to be greater than the top width of the upper stool.

3) Limitation of production: The thickness of corrugation plates must be equal to or smaller than 25 mm which is the bending limit.

4) Limitation by structural analysis: The compressive stress of the corrugation center must be smaller than the critical buckling stress, and the stress of the bottommost part of the corrugation must satisfy the permissible stress of each classification rule.

5) Limitation in consideration of workability: Brackets are installed at the bottom stool along the corrugation web (inclined plate) in product carrier. In this case, the brackets must not interfere with the diaphragm, and they must be separated by at least the minimum distance to enable manufacturing.

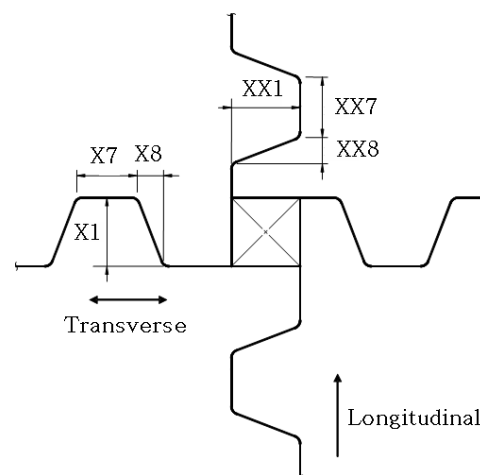


Figure 1. Design variables for optimum design.

Many transverse bulkheads have a lower stool that is perpendicular to the slope surface as shown in figure 2, and if a pipe trunk is additionally installed, many more cases must be considered compared to longitudinal bulkheads. This is because if the lower stool is perpendicular to the slope surface, the coordinate where the bracket meets with longitudinal differs between odd and even number of corrugation pitches, and if a pipe trunk is added, the starting points of left and right corrugations around the centerline become different. These cases were all considered in this study.

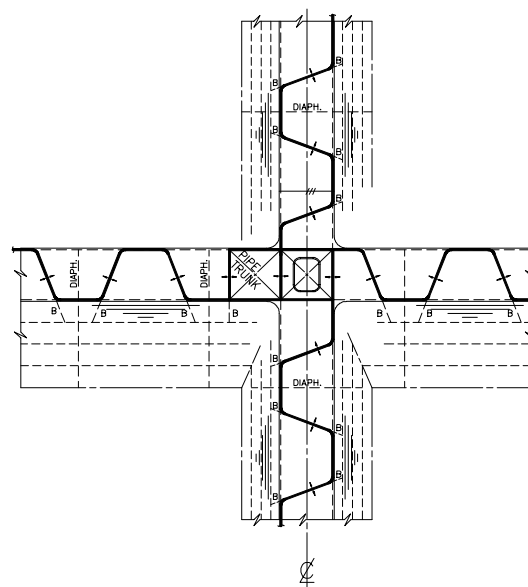


Figure 2. Design variables for optimum design.

Figure 3 shows an example of optimization results in case a pipe trunk is additionally installed, containing the design variables when the total weight of longitudinal and transverse bulkheads become the minimum, the optimum positions of bulkheads, the stress and permissible stress values of interested parts.

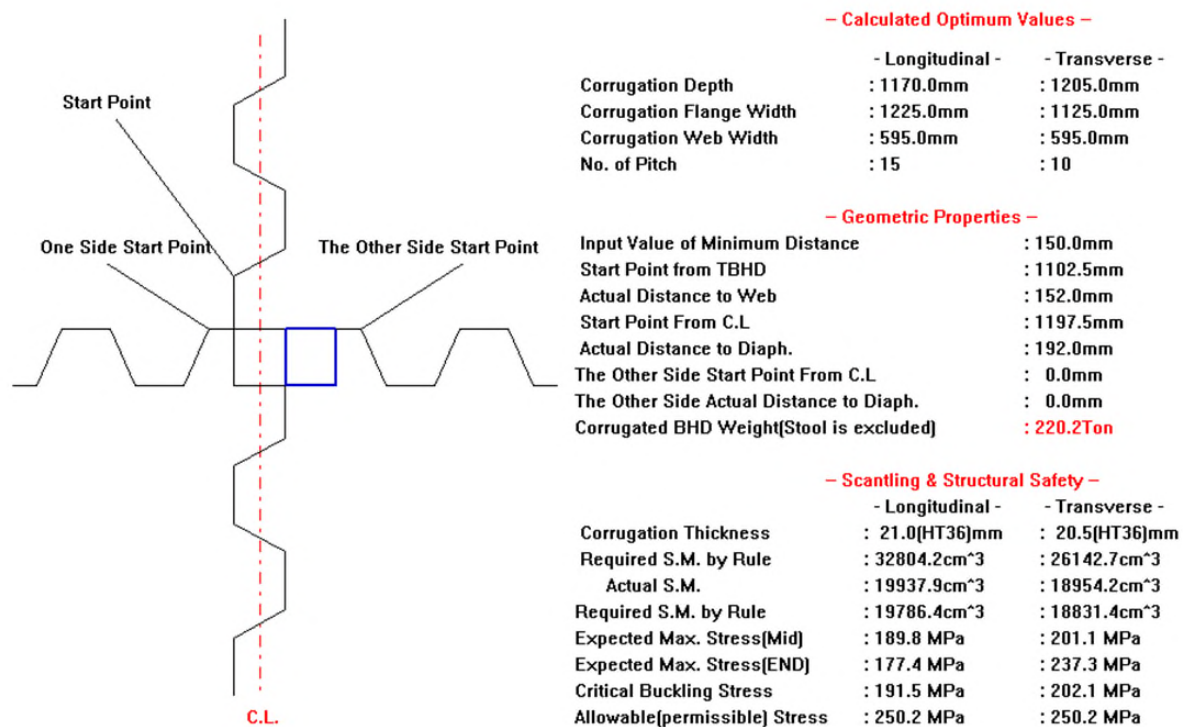


Figure 3. Example of optimization results in case a pipe trunk is additionally installed.

6. Results and discussion

The optimization results and original designed dimensions of the existing ship (70K product carrier) are compared and summarized in table 1. The optimization result showed about 3% reduction in weight compared to the existing ship designed in accordance with the DNV classification requirements. This effect is meaningful because the workability was also taken into consideration.

Table 1. Comparison of optimum results.

Design Variables	Dimension [mm]	
	Optimized Results	Original Design (DNV class)
X1	1,120	1,150
X7	1,115	1,150
X8	455	430
XX1	1,130	1,150
XX7	1,215	1,240
XX8	500	480
Weight [ton]	162.5	167.2
Ration [%]	97.2	100

As mentioned above, weight in table 1 is for the corrugated bulkheads per one cargo hold excluding the stool structures. The weight reduction effect per ship of 70K product carrier is about 26 ton. Comparison with the existing ship designed in accordance with the requirements of other classifications need to be studied.

7. Conclusions

In this study, optimum design of corrugated bulkhead for product carrier was conducted. And the following conclusions were obtained:

The problem of search time for global optimum point was solved by applying ESM which is excellent for global optimum point search and beam elements based on GSDM in repeated structural analysis. The results were obtained within just a few minutes.

The proposed optimization technique in this study improved the practicality by making even the design variables that give minimum weight to be eliminated if they violate workability.

The weight reduction of 26 ton per ship of 70K product carrier was obtained. It is also expected that proposed technique will considerably contribute to the saving of design man-hours.

8. References

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