Invited Paper

Development of an optimum structural design system for double hull VLCC

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Abstract

An optimum structural design system for double hull VLCC is developed based on the generalized slope deflection method for the direct calculation and the Hooke & Jeeves direct search method for the optimum design.

By dividing the ship structures into longitudinal members, transverse web frame members and transverse bulkhead members, the longitudinal members are designed by the classification rules such as DnV, Lloyd and the transverse web frame members and the transverse bulkhead members are designed by the generalized slope deflection method which incorporated axial deformations into the existing slope deflection method.

By this system, several minimum hull weight designs of double hull VLCC of 300,000 DWT are performed. And the design results are compared with existing ships and the automatic drawing of midship section is also provided.

1. Introduction

In recent years, more attentions have been paid to the protection of the sea from oil pollution due to the several disastrous oil spills by shipwrecks of large crude oil tankers.

Although oil tankers with double side structures have been developed to meet the I.M.O. regulations (MARPOL 73/78) for the protection from marine pollution that came into effect in 1981, it is also of great necessity for most shipyards to develop new types of tankers with double bottom and double side structures since more strengthened regulations on marine pollution have been
recently adopted by the U.S. Congress and I.M.O.

For the conventional oil tankers, many attempts have been made to perform optimum designs of ship structures. The Authors also suggested some efficient approaches to the optimum structural design of conventional oil tankers and double hull oil tankers[1-5].

The optimum designs of longitudinal members by classification rules have been widely used to the actual design stage. However, the optimum designs of transverse members are still far from the practical design applications since a number of direct calculations for the transverse strength analysis are needed in design optimization. For the transverse strength analysis of ship structures, the 3-D coarse mesh finite element analysis for several consecutive cargo holds and 2-D fine mesh analysis of transverse web frame are usually carried out[6], but they are extremely inefficient for the actual design purpose since tremendous computation efforts and cost are required during a considerable number of design iterations for optimization.

The generalized slope deflection method[7~11] is developed to overcome above difficulties by considering the effects of axial deformations from the existing slope deflection method and the bracketed end connections of actual ship structures.

An optimum structural design system for double hull VLCC is developed based on the generalized slope deflection method and the Hooke & Jeeves direct search method[12] is adopted to easily find discrete design variables of actual ship structures.

An actual double hull VLCC of 300,000 DWT is adopted to verify the effectiveness of the program. The longitudinal members are designed by the classification rules such as DnV, Lloyd and the transverse web frames and bulkheads members are designed by the generalized slope deflection method.

Three tank types(TYPE I, II, III) are considered according to the number of longitudinal bulkhead in cargo tanks. The numbers of longitudinal bulkhead in cargo tanks are zero, one, two respectively. Total hull weight of optimum design is calculated and compared with that of existing design ship.

From the sample calculations, an optimum structural design is suggested from the viewpoint of classification rules and tank types. Also, the obtained design results are brought out on the scantling sheet of each society for design approval and the automatic drawing of midship section is provided.

2. Minimum Weight Design of Longitudinal Strength Members

The minimum weight design procedure of longitudinal members is as follows. All the scantlings of longitudinal members such as the plates and the longitudinals except the deck part can be determined by the rule minimum requirements and the deck part members should be designed to minimize the midship section area which satisfies longitudinal hull girder strength.
2.1 Objective function
The objective function is the midship section area of the midship part of ship.

2.2 Design variables
Deck thickness is adopted as a primary design variable since the bottom structures are generally heavier than deck structures in the double hull VLCC.

2.3 Constraints
It is considered that the deck thickness should not be smaller than the rule minimum thickness and also the hull section modulus should not be smaller than the rule minimum hull section modulus as follows:

\[
G(1) = \left( T_D \right)_C \left/ \left( T_D \right)_R \right. - 1 \geq 0 \quad \text{(local strength for deck thickness)} \\
G(2) = \left( SMB \right)_C \left/ \left( SMB \right)_R \right. - 1 \geq 0 \quad \text{(longitudinal strength at bottom)} \\
G(3) = \left( SMD \right)_C \left/ \left( SMD \right)_R \right. - 1 \geq 0 \quad \text{(longitudinal strength at deck)}
\]

where \((\_)_C\) : Current value
\((\_)_R\) : Required value

2.4 Optimization technique
The Hooke & Jeeves direct search method combined with the external penalty function method which can search the optimum point by local search and pattern move is adopted to obtain discrete design variables easily.

2.5 Design results and discussions

Figure 1: Existing Design Ship(300K D/H Tanker:DnV Classification)
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As shown in Figure 1, the sample design ship is selected from the recently built existing double hull VLCC of 300,000 DWT DnV classification vessel. As shown in Figure 2, 3, the results obtained by the minimum weight design of the longitudinal members are similar to those of existing ship. Also, a small difference in scantlings is found between the DnV and Lloyd classification.

3. Minimum Weight Design of Transverse Strength Members

The minimum weight design procedure of transverse members by direct calculation is as follows. The midship part of ship structures for one web space is modelled as a web frame structure using beam elements. The generalized slope deflection method is adopted to obtain the member stresses such as bending, shear and equivalent stress. The transverse members are designed to minimize the volume of web frame which satisfies allowable stresses.

3.1 Generalized slope deflection method

As shown in Figure 4, when the bracketed beam is deformed under distributed loads, end moments and forces, the generalized slope deflection equations can be derived by Castigliano theorem as follows.
Figure 4: Bracketed Beam for GSDM(2-D)

\[ M_A = 2EI_0/L \left[ 2F_A \theta_A + G_A \theta_B - (2F_A + G_A)\phi \right] - m_A \]
\[ M_B = 2EI_0/L \left[ 2F_B \theta_B + G_B \theta_A - (2F_B + G_B)\phi \right] + m_B \]
\[ S_A = -(M_A + M_B)/L + W (L - a)/L \]
\[ S_B = S_A - W \]
\[ P_A = EA (u_A - u_B)/L_A \]
\[ P_B = P_A \]

where, \( F_A, F_B, G_A, G_B \) are coefficients to express the bracket effect and \( m_A, m_B \) are fixed end moments[10].

3.2 Objective function
The objective function is the sum of the volume of uniform beams and bracketed parts except shell plates.

3.3 Design variables
The web thickness of each member is selected as design variables. To reduce the design variables the plate flange thickness is assumed same as that of shell plate. And the web height, flange breadth and thickness for single structures are assumed parametric design variables.

3.4 Constraints
As for constraints, the maximum equivalent and shear stress in each member should not exceed the allowable equivalent and shear stress in each member, and also the minimum thickness for each member to prevent web buckling is considered as follows.

\[
\begin{align*}
G(j + 1) &= \frac{\sigma_a}{\sigma_i} - 1 \geq 0. \quad \text{(bending)} \\
G(j + 2) &= \frac{\tau_a}{\tau_i} - 1 \geq 0. \quad \text{(shear)} \\
G(j + 3) &= \frac{T_i}{T_{\text{min}}} - 1 \geq 0. \quad \text{(buckling)}
\end{align*}
\]

where \( i = 1, 2, \ldots, NE \)
\( j = (i - 1) \times 3 \)

- \( NE \): number of elements
- \( \sigma_a \): allowable equivalent stress
- \( \sigma_i \): member equivalent stress
- \( \tau_a \): allowable shear stress
- \( \tau_i \): member shear stress
- \( T_i \): web thickness
- \( T_{\text{min}} \): minimum thickness to prevent buckling

3.5 Design results and discussions
As shown in Figure 5, 6, the design values obtained by the minimum weight design of the transverse members are similar to those of existing ship. From the comparison between Figure 5 and Figure 6, we can see that DnV requires comparatively heavier transverse members in the wing tank while Lloyd requires more scantlings of deck web in the center tank of double hull oil tanker.
4. Minimum Weight Design of Transverse Bulkhead Members

As the typical types of transverse bulkhead, plane types and corrugated types are widely used. The formers are mainly used for large tankers and the latters are mainly used for bulk carriers and small tankers. Plane type bulkheads which have stringer and plane part adopted in this paper can be modelled as a grillage model using beam elements. The members of stringer part are designed to minimize the volume which satisfies the allowable stresses and the members of plane part are designed by the rule minimum requirements.

4.1 Objective function
The objective function is the sum of the volume of stringer and plane part.

4.2 Design variables
Design variables are the height, the breadth of flanges and the thickness of stringer part.

4.3 Constraints
As for constraints, the maximum bending and shear stress should not exceed the allowable equivalent and shear stress for stringer part, and also the minimum thickness to prevent web buckling and yielding is considered as shown in Eqn.(3).

4.4 Design results and discussions
As shown in Figure 7, 8, the design values obtained by the minimum weight design of the transverse bulkhead members are similar to those of existing ship. Also, the design values are similar between the DnV and Lloyd classification.

![Figure 7: Present Design for Trans. BHD Member(DnV Base)](image1)

![Figure 8: Present Design for Trans. BHD Member(Lloyd Base)](image2)
5. Minimum Weight Design of Cargo Hold Part

As shown in Figure 9, the optimum tank arrangement can be obtained by taking into consideration of the tank length, web space and the location of longitudinal bulkheads.

Three tank types (TYPE I, II, III) are considered according to the number of longitudinal bulkhead in cargo tanks except double side structure. The numbers of longitudinal bulkhead in cargo tanks are zero (0), one (1), two (2) respectively. From the given cargo hold length except fore and aftbody the cargo hold weight can be obtained by the summation of the longitudinal weight \( W_l \), the transverse weight \( W_t \) and the transverse bulkhead weight \( W_b \).

5.1 Hull weight estimation

The hull weight can be obtained by the summation of the cargo hold weight, forebody weight \( W_f \), aftbody weight \( W_a \).

The forebody and aftbody weight can be estimated by the estimation formula as follows.
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Hullweight (Ton) = Wl + Wt + Wb + Wf + Wa (4)

where

\[ Wl = (W_{l} \times L_{h}) \times \left\{ 0.4 + 0.6 \left( 3 + \frac{C_{B}}{1000} \right) \right\} \]

\[ Wt = (W_{tc} \times N_{tc} + W_{tw} \times N_{tw}) \times \left\{ 0.4 + 0.6 \left( 3 + \frac{C_{B}}{1000} \right) \right\} \]

\[ Wb = (W_{bc} \times N_{bc} + W_{bw} \times N_{bw}) \]

\[ Wf = 160 \times (L_{f} \times B \times D \times \frac{C_{B}}{1000})^{0.728} \]

\[ Wa = 530 \times (L_{a} \times B \times D \times \frac{C_{B}}{1000})^{0.469} \]

\( W_{l} \): weight of longitudinal members per unit length

\( W_{tc}, W_{tw} \): weight of web frames in cargo and wing tanks

\( N_{tc}, N_{tw} \): number of web frames in cargo and wing tanks

\( W_{bc}, W_{bw} \): weight of transverse bulkheads in cargo and wing tanks

\( N_{bc}, N_{bw} \): number of transverse bulkheads in cargo and wing tanks

5.2 Objective function

The objective function is defined as the hull weight mentioned above.

5.3 Design variables

The number of transverse bulkheads, the number of web frames and the location of longitudinal bulkhead are adopted as parametric design variables.

5.4 Constraints

As for constraints, the MARPOL(SBT, PL etc.) convention is adopted for the tank arrangement and is to be checked by the package program SIKOB.

5.5 Design results and discussions

As shown in Table 1, the hull weight is estimated by the summation of the longitudinal weight, transverse weight, transverse bulkhead weight, forebody weight and aftbody weight for the DnV and Lloyd classification.

We can see that the hull weights obtained by the DnV and Lloyd rules are similar without respect to tank types but the hull weights obtained by the tank types are quite different.

TYPE I requires about 20%, TYPE II requires about 15% and TYPE III requires about 13% overweight on the basis of hull weight for the conventional tanker of 300,000 DWT(28,500 Ton)[3]. Therefore, it can be said that TYPE III is proper for the structural design of double hull VLCC.

Conclusively, from the structural design viewpoint, several comparative studies should be done for the determining optimum tank arrangement and tank type according to ship sizes.
Table 1 Comparison of Hull Weight with Existing Ship

<table>
<thead>
<tr>
<th></th>
<th>CLASS</th>
<th>TYPE I</th>
<th>TYPE II</th>
<th>TYPE III</th>
</tr>
</thead>
<tbody>
<tr>
<td>Long. Weight</td>
<td>DnV</td>
<td>16603</td>
<td>17559</td>
<td>18597</td>
</tr>
<tr>
<td></td>
<td>Lloyd</td>
<td>16657</td>
<td>17608</td>
<td>18651</td>
</tr>
<tr>
<td>Trans. Weight</td>
<td>DnV</td>
<td>3024</td>
<td>6613</td>
<td>5598</td>
</tr>
<tr>
<td></td>
<td>Lloyd</td>
<td>3276</td>
<td>6760</td>
<td>5000</td>
</tr>
<tr>
<td>T. BHD Weight</td>
<td>DnV</td>
<td>8344</td>
<td>3178</td>
<td>2648</td>
</tr>
<tr>
<td></td>
<td>Lloyd</td>
<td>9248</td>
<td>3104</td>
<td>2757</td>
</tr>
<tr>
<td>Forebody Weight</td>
<td>DnV</td>
<td>1446</td>
<td>1446</td>
<td>1446</td>
</tr>
<tr>
<td></td>
<td>Lloyd</td>
<td>4002</td>
<td>4002</td>
<td>4002</td>
</tr>
<tr>
<td>Afterbody Weight</td>
<td>DnV</td>
<td>33419</td>
<td>32798</td>
<td>32291</td>
</tr>
<tr>
<td></td>
<td>Lloyd</td>
<td>34629</td>
<td>32920</td>
<td>31855</td>
</tr>
</tbody>
</table>

Note) Weight of Existing Ship (=32700 Ton)
(TYPE III:DnV Base)

As shown in Figure 10, the optimum scantlings are expressed according to the scantling format for the DnV classification approval. Also, as shown in Figure 11, optimum design results obtained by the DnV classification rules are drawn by the graphic library PLOT10.

Figure 10: Example of Scantling Sheet(TYPE III:DnV Base)
Figure 11: Midship Section Drawing (TYPE III: DnV Base)
6. Conclusions

For the optimum structural design of double hull VLCC, minimum weight design programs are developed by using the Hooke & Jeeves direct search method for the DnV and Lloyd rules.

The longitudinal members are designed by the classification rules such as DnV, Lloyd and the transverse web frames and bulkheads members are designed by the generalized slope deflection method. Three tank types are considered according to the number of longitudinal bulkhead in cargo tanks. Total hull weight of optimum design is calculated and compared with that of existing design ship.

The main conclusions can be summarized as follows.

1. The obtained scantlings and hull weight between the DnV and Lloyd classification rules are similar from the viewpoint of classification.
2. The hull weights for TYPE II, III are similar but that of TYPE I is heavier than those of TYPE II, III from the viewpoint of tank type and it can be suggested that TYPE III is proper for the structural design of double hull VLCC.
3. Several comparative studies are necessary to determine the proper tank arrangement according to ship sizes.
4. A minimum cost design of double hull tanker will be studied in future to reduce the fabrication cost.

References

7. Jang, C.D. and Na, S.S., "On the Minimum Structural Weight Design of


