Effect of profile element dimension to the ultimate hull girder strength

P A N Lestari¹, Ashury¹, M Z M Alie¹ and S Wairara²

¹Department of Ocean Engineering, Engineering Faculty, Universitas Hasanuddin, Makassar, Indonesia
²Department of Aquatic Resources Management, Faculty of Agriculture, Universitas Musamus, Merauke, Indonesia

Email: zubair.m@eng.unhas.ac.id

Abstract. The hull girder plays an important role against those loads and to describe the structural behavior under longitudinal bending. The hull cross-sectional properties have a significant contribution to the ultimate strength investigation. Therefore, the influence of the element section properties to the ultimate hull girder strength must be evaluated. The objective of the present study is to calculate the ultimate hull girder strength considering the element section properties subjected to longitudinal bending. Two double-hull tankers are taken with the same dimension, but different from the element section properties characteristic such as number, dimension, and type of the stiffeners located on the bottom, shell and deck parts. The basic formula is adopted to calculate element section properties of the hull girder for double hull tanker. The double hull tanker is modeled as a cross-section having the stiffeners and attached plating. The stress due to the difference of the element section properties is less than allowable stress.

1. Introduction

The longitudinal strength is the most important aspect of ship design. To know the longitudinal strength of the ship, the calculation and evaluation must be conducted. These may be used as an analytical solution or numerical calculation. Classically, the longitudinal strength of the ship is analyzed by considering the beam theory approach. However, the other procedure may also be implemented as mentioned before.

The longitudinal strength analysis of ship has been done by many researchers particularly for tanker and bulk carrier. The residual strength of an Aframax-class double hull oil tanker damaged in the collision had been assessed by Parunov [1] by considering the influence of the rotation of the neutral axis. The influence of nonlinear finite element method models on the ultimate bending moment for hull girder was studied by Xu [2]. There was two analysis were performed, those were implicit static analysis and explicit dynamic analysis. A structural reliability analysis model based on a Bayesian belief network was proposed by Li and Tang [3] for the hull girder collapse risk after accidents. The Bayesian belief network was used to represent random states of variable risk events after accidents, as well as the dependencies between events, and the structural reliability analysis was used to evaluate the failure probability hull girder for each possible accident conditions. The incidence of collision damage models on an oil tanker and bulk carrier reliability was investigated by Campanile [4] considering the IACS deterministic model against GOLADS/IMO database statistics for collision events, substantiating the probabilistic model. Reliability of an oil tanker in intact condition was performed by Campanile [5] to investigate the incidence of load combination methods on hull girder...
sagging/hogging time-variant failure probability. The simplified approach on the ultimate hull girder strength of asymmetrically damaged ships was conducted by Muis Alie [6] considering the critical element under sagging condition. The residual hull girder strength in intact and damage condition under longitudinal bending moment using nonlinear finite element was conducted by Muis Alie [7], and damages were modeled simply by removing the element on the damaged part. The ultimate hull girder strength considering section modulus under longitudinal bending was analyzed by Muis Alie and Latumahina [8] and the cross-section of Ro-Ro ship was taken to be analyzed.

The comparative study of the element section properties to the hull girder ultimate strength on double hull tanker is studied. Two double-hull tankers are considered having same dimensions, but different characteristics for the element section properties such as number, dimension, and type of stiffeners located at the deck, inner and outer side shell and bottom part. The simplified calculation method is adopted to analyze the ultimate strength of double hull tanker. The influence of the characteristics is presented for number, dimension and type of the stiffeners to the ultimate hull girder strength.

2. Basic formula

The primary hull girder bending depends on the element composed of stiffened and unstiffened plates. The number, dimension, and type of the plate and stiffened plates give a contribution to the longitudinal strength. Therefore, these configurations should be analyzed for the design purpose. Figure 1 shows the cross-section of double hull tanker and figure 2 the typical type of stiffened plate with attached plating.

![Figure 1. Cross-section of Double Hull Tanker](image)

![Figure 2. A typical type of stiffened plate with attached plating](image)

Figure 2 shows the element composed of the stiffened plate and attached plating including the neutral axis (N-A). The calculation of the inertia moment of the element may be expressed as
\[ I = \frac{b_p}{12} \left( t_p \right)^3 + A_p \left( z_p - \frac{t_p}{2} \right)^2 + \frac{h_u^3}{12} + A_w \left( z_p - \frac{h_u}{2} \right)^2 + \frac{b_f t_f^3}{12} + A_f \left( \frac{t_p + h_u + t_f - z_p}{2} \right)^2 \]  \tag{1}

Where \[ A_p = b_p t_p \]
\[ A_w = h_u t_w \]
\[ A_f = b_f t_f \]

\[ z_p = \frac{0.5 b_p t_p^2 + A_w \left( t_p + 0.5 h_u \right) + A_f \left( t_p + h_u + 0.5 t_f \right)}{A_p + A_w + A_f} \]  \tag{2}

The position of the neutral axis (N-A), \( g \), as shown in figure 1 may be obtained by assuming that all longitudinal strength elements of the cross-section are fully effective, thus

\[ g = \frac{\sum A_i z_i}{\sum A_i} \]  \tag{3}

Where \( A_i \) is the cross-sectional area of the \( i \)th plate stiffener element with fully attached plating and \( z_i \) is the coordinate of the \( i \)-th element, \( z = 0 \) is taken at the baseline. The moment of inertia of the hull cross-section is calculated by the following formula

\[ I_y = \sum A_i (z_i - g)^2 + \sum y_i \]  \tag{4}

Where \( i y_i \) is the moment of inertia of each element such as stiffener, plate between stiffeners concerning the neutral axis of each element. The section modulus at the deck and bottom part denoted by \( W_D \) and \( W_B \) are given by

\[ W_D = \frac{I_y}{D - g} \]  \tag{5}

\[ W_B = \frac{I_y}{g} \]  \tag{6}

where \( D \) represents as the ship’s depth. The stress components on deck and bottom part can be obtained by using simple expression as follow,

\[ \sigma = \frac{M g}{I} \]  \tag{7}

\[ \sigma = \frac{M}{W} \]  \tag{8}

Where \( M \) is the moment on the deck or bottom part in hogging and sagging conditions. The bending moment may be used either for equation (7) or (8).
3. Ship properties
The ultimate hull girder strength analysis taking the influence of number, dimension, and type of the element section properties into consideration is conducted. Two double hull tanker is taken having the same particular dimension but different for dimension and type of the element section properties at the bottom, sides hell, and deck part of the cross-section. In the present study, the calculation of the element section properties is conducted for half part because the cross-section is symmetric. The difference is marked by the color lines at bottom, inner and outer side shell and deck part including the longitudinal bulkhead at the cantor part of the cross-section. The half cross-section of double hull tanker for type-1 and type-2 are shown in figures 3 and 4.

Figure 3. Double hull tanker type-1

Figure 4. Double hull tanker type-2
4. Results and Discussion

The longitudinal strength of double hull tanker is calculated in hogging and sagging conditions for intact only. The still water, wave, and total vertical bending moment donated by $M_{SW}$, $M_{W}$, and $M_{T}$, respectively and calculated as follow [9]:

Hogging condition:

\[ M_{SW} = 0.01 K_{M} C L^{2} B C_{b} (11.97 + 1.9 C_{b}) \]  
(9)

\[ M_{W} = 0.19 K_{M} C L^{2} B C_{b} \]  
(10)

\[ M_{T} = M_{SW} + M_{W} \]  
(11)

Sagging condition:

\[ M_{SW} = -0.05168 K_{M} C L^{2} B (C_{b} + 0.7) \]  
(12)

\[ M_{W} = -0.11 K_{M} C L^{2} B (C_{b} + 0.7) \]  
(13)

\[ M_{T} = M_{SW} + M_{W} \]  
(14)

Where $L$, $B$ and $C_{b}$ are the length, breadth, and block coefficient of the ship, respectively. While $M_{W} = 1$ and $C$ is calculated using this formula:

\[ C = 10.75 - \left[ \frac{(300 - L)}{100} \right]^{1.5} \text{for} 90 \leq L \leq 300 \text{m} \]  
(15)

It should be noted that the dimension of double hull tanker type-1 and type-2 is equal, including the material properties. Based on the calculation using the above formula, the still water, wave and total vertical bending moment under hogging and sagging conditions are summarized in table 1 as follow:

| Items | Hogging $\times 10^{12}$ (Nmm) | Sagging $\times 10^{12}$ (Nmm) |
|-------|-------------------------------|------------------------------|
| $M_{SW}$ | 2.581                         | -1.882                       |
| $M_{W}$  | 3.647                         | -4.013                       |
| $M_{T}$  | 6.957                         | -6.698                       |

The longitudinal bending moment obtained by the basic formula of double hull tanker for type-1 and type-2 is summarized in table 2 as follow:

| Items | Type-1 | Type-2 |
|-------|--------|--------|
| $M_{U}$ Hogging $\times 10^{12}$ (Nmm) | 5.750 | 6.522 |
| $M_{U}$ Sagging $\times 10^{12}$ (Nmm)  | -6.089 | -6.137 |
According to table 2, type-1 and type-2 of double hull tanker for the comparison purposes, the longitudinal bending moment obtained from the table 1 is therefore compared to the longitudinal bending moment obtained by the basic formula in table 2. It is observed that the longitudinal bending moment obtained by the basic formula is smaller than in table 1 in hogging and sagging condition for both type-1 and type-2 of double hull tanker. It is observed that the longitudinal bending moment occurs at the bottom and deck part is under the allowable requirement. For the allowable working stress, the bottom and deck part in hogging and sagging conditions are shown in table 3 as follow

| Items     | Hogging (N/mm²) | Sagging (N/mm²) |
|-----------|----------------|-----------------|
| Deck      | 250            | 250             |
| Bottom    | 180            | 180             |

Table 4. Working stress of double hull tanker type-1

| Items     | Hogging (N/mm²) | Sagging (N/mm²) |
|-----------|----------------|-----------------|
| Deck      | 161,158         | 155,162         |
| Bottom    | 116,527         | 112,192         |

Table 5. Working stress of double hull tanker type-2

| Items     | Hogging (N/mm²) | Sagging (N/mm²) |
|-----------|----------------|-----------------|
| Deck      | 181,608         | 174,852         |
| Bottom    | 125,617         | 120,944         |

Table 4 and 5 show that the working stress acting on the deck and bottom part of double hull tanker for type-1 and type-2 is smaller than the allowable stress based on table 3. It indicates that the working stress occurs at the bottom and deck part for hogging and sagging conditions are under the allowable requirement.

5. Conclusions
The longitudinal hull girder strength analysis of double hull tanker considering element section properties under hogging and sagging conditions have been performed based on the basic formula. Those results are compared to the formula described in classification rules. According to these results, the following conclusions may be taken as follow; the influence of the element section properties on the longitudinal hull girder strength is significant on the double hull tanker. The longitudinal bending moment and the allowable working stress occurs on the deck and bottom part under hogging and sagging conditions are smaller than a formula by the classification rules. It indicates that the longitudinal bending moment and working stress under the allowable requirement.

References
[1] Parunov J, Rudan S and Bužančić Primorac B 2017 Residual ultimate strength assessment of double hull oil tanker after collision Eng. Struct. 148 704–17
[2] Xu M C, Song Z J and Pan J 2017 Study on influence of nonlinear finite element method models
on ultimate bending moment for hull girder Thin-Walled Struct. 119 282–95
[3] Li X and Tang W 2019 Structural risk analysis model of damaged membrane LNG carriers after grounding based on Bayesian belief networks Ocean Eng. 171 332–44
[4] Campanile A, Piscopo V and Scamardella A 2018 Conditional reliability of bulk carriers damaged by ship collisions Mar. Struct. 58 321–41
[5] Campanile A, Piscopo V and Scamardella A 2017 Incidence of load combination methods on time-variant oil tanker reliability in intact conditions Ocean Eng. 130 371–84
[6] Muis Alie M Z 2018 Simplified approach on the ultimate hull girder strength of asymmetrically damaged ships Int. J. Offshore Polar Eng. 28 200–5
[7] Muis Alie M Z, Sitepu G, Sade J, Mustafa W, Nugraha A M and Bin Muh. Saleh A 2016 Finite Element Analysis on the Hull Girder Ultimate Strength of Asymmetrically Damaged Ships V003T02A083
[8] Muis Alie M Z and Latumahina S I 2018 The Ultimate Hull Girder Strength Analysis Considering Section Modulus Under Longitudinal Bending 581–7