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Collapse Analysis on VLCC Subjected to Longitudinal Bending with Damages

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Abstract. The objective of the present study is to analyze the progressive collapse of VLCC hull girder with damages subjected to longitudinal bending. For the simple case, the cross-section is assumed to be remained plane and the vertical bending moment is applied to the cross section. The residual stress, initial imperfection, and crack are not considered. The damages scenarios are located at the center part and asymmetric position of the cross section. To analyze the progressive collapse including its behavior of VLCC ship hull, the simply supported is imposed to the cross section and taking the hogging and sagging condition into account. The results obtained for intact and damages condition by the analytical solution is compared and summarized with one another.

Introduction

Grounding and collision damages may occur on ship when it operates at sea. The grounding and collision accidents of liquid cargo such as crude oil carriers effect the ship structure becomes damage and the oil spills makes the ocean environment polluted. In conjunction with this, the design of ship structure must be considered as one of the functional requirement for structural safety.

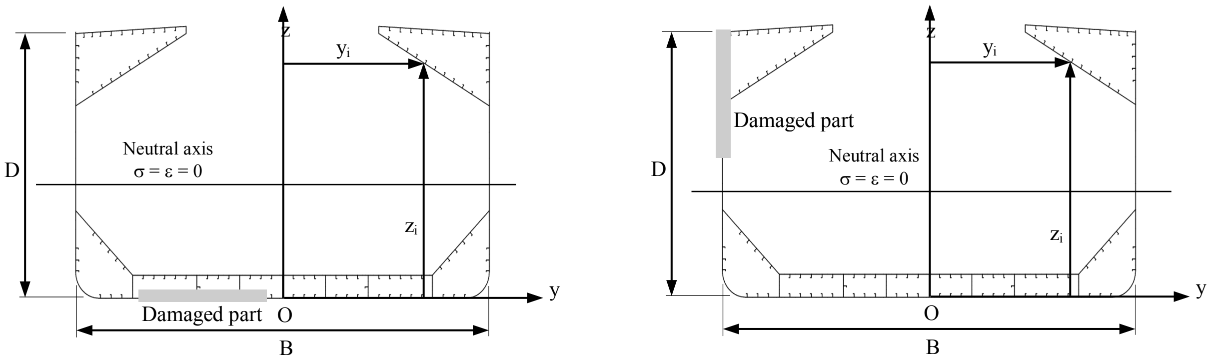
The investigations of ship damage due to grounding and collision have been conducted by some research. The mechanics of grounding on relatively plane slopes were analyzed with emphasis on evaluation of the overall forces on the ship hull girder was presented by Pedersen [1]. To get at much insight as possible into the mechanics of ship grounding, simplifications to the problem were sought such that analytical solutions could be derived. The same assumption as that used in the method of Wierzbicki and Thomas for a separated curved surface was employed by Zhang [2], in which the material rolls up into two curved surfaces behind the wedge tip. Damage to ship bottom in grounding accident is quite complex. So, a semi empirical method was proposed for determining bottom damage resistance in grounding scenario. Finally, simple expression, expressed in terms of the ship's principal particulars, for determining damage resistance and damage extent in ship grounding were presented. An investigation of the longitudinal strength of damaged ship hulls for a broad spectrum of collision and grounding accidents was reported by Wang [3]. Both the hull girder section modulus and hull girder ultimate strength were calculated. The aim is to obtain simple relations to assess residual hull girder strength, which may be used as handy and reliable tools to help make timely decisions in the event of an emergency. Muis Alie, M.Z [4] analyzed the residual strength of asymmetrically damaged ship hull girder under longitudinal bending. Beam finite element method was used for the assessment of residual strength of two single hull bulk carriers and a three-cargo hold model of a single-side Panamax Bulk Carrier in hogging and sagging conditions. A fast and reasonably accurate method for exploring the collapse of hull girder in the damage condition was developed by Paik [5]. Location and amount of collision and grounding damage were defined based on the ABS safe hull guide. To characterize residual strength, an elastic section modulus based residual strength index and an ultimate bending strength based residual strength index were defined. As an illustrative example, these indices were obtained for the hull girder collapse of a hypothetical Panamax class bulk carrier after collision and grounding.

In the present study, a VLCC hull girder with damages subjected to longitudinal bending is analyzed. For the simple case, the cross-section is assumed to be remained plane and the vertical bending moment is applied to the cross section. The welding residual stress, initial imperfection, and crack are not considered. The damages scenarios are located at the center part and asymmetric position of the cross section. To analyze the progressive collapse including its behavior of VLCC ship hull, the simply supported is imposed to the cross section and taking the hogging and sagging condition into account. The results obtained for intact and damages condition by the analytical solution is compared and summarized with one another.

Analytical Formulation

Generally, damages due to grounding or collision are assumed to be located at an asymmetric position of a hull girder cross section as shown in Fig.1. The progressive collapse of ship hull girder subjected to longitudinal bending moment due to grounding and collision damages is calculated using some formulations in the analytical solution. Although the grounding or collision damages takes place at the asymmetric position, the cross section is assumed to be remained plane. In conjunction with this, the axial strain at the structural element caused by vertical and horizontal curvature can be expressed as,

$$\varepsilon_i(y_i, z_i) = \varepsilon_0 + y_i \phi_H + z_i \phi_V \tag{1}$$



(a) Grounding (b) Collision

Figure 1. Damages on the ship cross section.

where ε_0, ϕ_H and ϕ_V are the axial strain at the origin O, horizontal curvature and vertical curvature respectively. The y and z are the coordinates with the origin at the bottom keel are defined according to Fig. 1. The relationship between axial stress and axial strain to calculate the individual element can be expressed by the following equation

$$\sigma = f_i(\varepsilon) \tag{2}$$

where $f_i(0) = 0$. The axial force P, the vertical bending moment M_V and the horizontal bending moment M_H can be obtained by using the formulas:

$$\begin{aligned} P &= \sum_{i=1}^{N} \sigma_i A_i \cong 0 \\ M_V &= \sum_{i=1}^{N} \sigma_i A_i y_i \\ M_V &= \sum_{i=1}^{N} \sigma_i A_i x_i \end{aligned} \tag{3}$$

Those values are obtained by integrating the axial stress over the intact part of the cross section. Where N is the number of intact elements and A_i is a cross section of individual element. The tangential stiffness obtained as a slope of the average stress-average strain relationship of the individual element by D_i as shown in Fig. 2, the relationship of axial stress and strain can be expressed as,

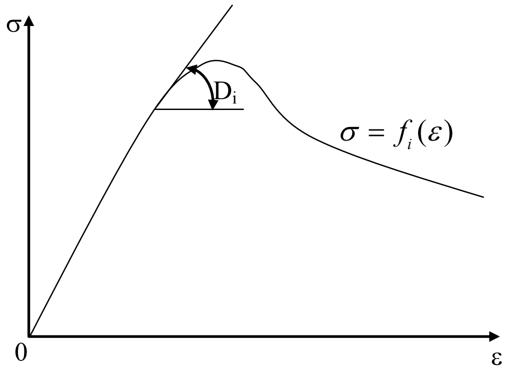


Figure 2. Average stress-average strain relationship of an element.

$$\Delta\sigma = D_i \Delta\varepsilon \left(D_i = \frac{df_i}{d\varepsilon} \right) \tag{4}$$

By performing Eqs. 1 and 4, the axial load, vertical curvature and horizontal curvature from Eq. 3 can be written into the matrix form as follow:

$$\begin{Bmatrix} \Delta P = 0 \\ \Delta M_H \\ \Delta M_V \end{Bmatrix} = \begin{bmatrix} \overline{D}_{AA} & \overline{D}_{AH} & \overline{D}_{AV} \\ \overline{D}_{HA} & \overline{D}_{HH} & \overline{D}_{HV} \\ \overline{D}_{VA} & \overline{D}_{VH} & \overline{D}_{VV} \end{bmatrix} \begin{Bmatrix} \Delta\varepsilon_0 \\ \Delta\phi_H \\ \Delta\phi_V \end{Bmatrix} \tag{5}$$

The axial force ΔP from Eq. 5 may be rearranged in the form

$$\begin{aligned} \Delta P &= \overline{D}_{AA}\Delta\varepsilon_0 + \overline{D}_{AH}\Delta\phi_H + \overline{D}_{AV}\Delta\phi_V \\ &= \sum_{i=1}^{N} D_i \left(\Delta\varepsilon_0 + y_i \Delta\phi_H + z_i \Delta\phi_V \right) A_i \\ &= \sum_{i=1}^{N} D_i \left\{ \Delta\varepsilon_G + (y_i - y_G)\Delta\phi_H + (z_i - z_G)\Delta\phi_V \right\} A_i \end{aligned} \tag{6}$$

where

$$\Delta\varepsilon_G = \Delta\varepsilon_0 + y_G \Delta\phi_H + z_G)\Delta\phi_V \tag{7}$$

y_G and z_G are given by

$$\begin{aligned} y_G &= \frac{\left(\sum_{i=1}^{N} y_i \, D_i \, A_i \right)}{\left(\sum_{i=1}^{N} D_i \, A_i \right)} \\ z_G &= \frac{\left(\sum_{i=1}^{N} z_i \, D_i \, A_i \right)}{\left(\sum_{i=1}^{N} D_i \, A_i \right)} \end{aligned} \tag{8}$$

The Eq. 5 can be written by assuming that under pure longitudinal bending $\Delta P = 0$, therefore,

$$\begin{Bmatrix} \Delta P = 0 \\ \Delta M_H \\ \Delta M_V \end{Bmatrix} = \begin{bmatrix} \overline{D}_{AA} & 0 & 0 \\ 0 & \overline{D}_{HH} & \overline{D}_{HV} \\ 0 & \overline{D}_{VH} & \overline{D}_{VV} \end{bmatrix} \begin{Bmatrix} \Delta \varepsilon_G \\ \Delta \phi_H \\ \Delta \phi_V \end{Bmatrix} \tag{9}$$

where

$$\begin{aligned} D_{AA} &= \sum_{i=1}^{N} D_i A_i & D_{HV} = D_{VH} &= \sum_{i=1}^{N} D_i (y_i - y_G)(z_i - z_G) A_i \\ D_{HH} &= \sum_{i=1}^{N} D_i (y_i - y_G)^2 A_i & D_{HH} &= \sum_{i=1}^{N} D_i (y_i - y_G)^2 A_i \end{aligned} \tag{10}$$

Using the Eq. 10, the relationship of the biaxial bending moments and curvatures can be given by the following formula,

$$\begin{Bmatrix} \Delta M_H \\ \Delta M_V \end{Bmatrix} = \begin{bmatrix} D_{HH} & D_{HV} \\ D_{VH} & D_{VV} \end{bmatrix} \begin{Bmatrix} \Delta \phi_H \\ \Delta \phi_V \end{Bmatrix} \tag{11}$$

The bending moment-curvature relationship, Eq. 11 can be applied to the ship hull girder strength by the following loading and/or constraint conditions. The first is the hull girder under pure vertical bending moment

$$\begin{Bmatrix} 0 \\ \Delta M_V \end{Bmatrix} = \begin{bmatrix} D_{HH} & D_{HV} \\ D_{VH} & D_{VV} \end{bmatrix} \begin{Bmatrix} \Delta \phi_H \\ \Delta \phi_V^0 \end{Bmatrix} \tag{12}$$

where the superscript '0' indicates a prescribed value, and the solutions are:

$$\begin{aligned} \Delta \phi_H &= -\frac{D_{HV}}{D_{HH}} \Delta \phi_V^0 \\ \Delta M_V &= \left(D_{VV} - \frac{D_{VH} D_{HV}}{D_{HH}} \right) \Delta \phi_V^0 \end{aligned} \tag{13}$$

The second is the hull girder under vertical bending moment with horizontal curvature constrained,

$$\begin{Bmatrix} \Delta M_H \\ \Delta M_V \end{Bmatrix} = \begin{bmatrix} D_{HH} & D_{HV} \\ D_{VH} & D_{VV} \end{bmatrix} \begin{Bmatrix} 0 \\ \Delta \phi_V^0 \end{Bmatrix} \tag{14}$$

and the solutions are:

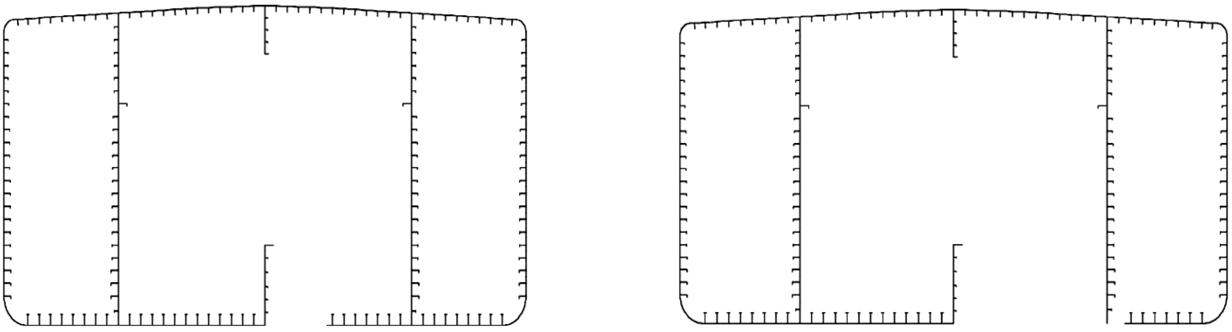
$$\begin{aligned} \Delta M_H &= D_{HV} \Delta \phi_V^0 \\ \Delta M_V &= D_{VV} \Delta \phi_V^0 \end{aligned} \tag{15}$$

Method of Analysis

Collapse analysis of the ship hull girder with grounding and collision damages are performed using the Smith's method. A VLCC of tanker is taken for the assessment of the collapse analysis. The ship breadth and high are 42000 mm and 20300 mm, respectively. The grounding damage is assumed to be asymmetric position of the cross section. The transversal damage extent is chosen 10% and 70% of the ship's breadth. For the case of collision damage, the transversal damage extent is B/16, while the vertical damage extent is set up to be 10% and 70%, respectively. The longitudinal damage extent is one-frame space for grounding and collision damages. The analysis procedures of the collapse analysis of VLCC tanker for grounding and collision damages are summarized as follows:

1. Subdivide the cross-section into elements consists of stiffener and attached plating.
2. Derive the average stress-average strain relationship of individual element by considering the influence of buckling and yielding.
3. Derive the tangential axial stiffness of individual element from the average stress-average strain relationship.
4. Calculate the center position of neutral axis y_G and z_G
5. Evaluate the flexural stiffness of the cross section with respect to neutral axis.
6. Calculate the curvature and/or bending moment under specified condition.
7. Calculate the strain in individual element from the curvature, and their stress using the slope of average stress-average strain curve.

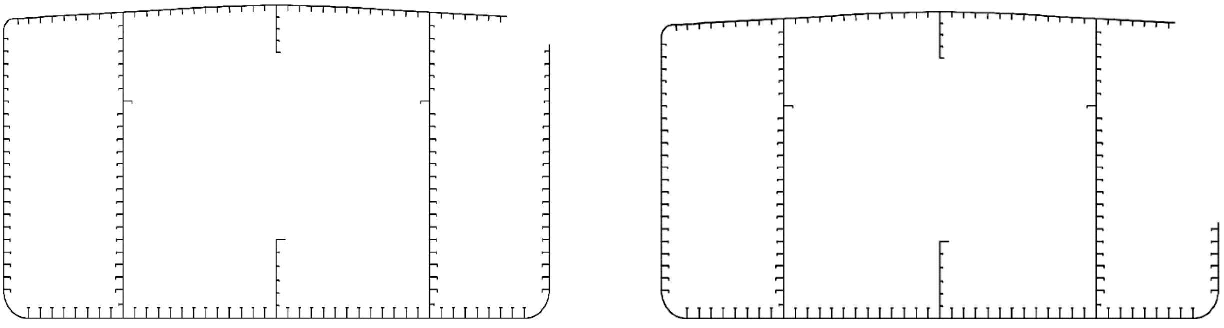
The grounding damages for 10% and 70% of VLCC tanker are presented in the Fig. 3 as follows:



(a) 10 % damage (b) 70% damage

Figure 3. Grounding damage of VLCC Tanker.

while the collision damages for 10% and 70% of VLCC tanker are presented in the Fig. 4 as follows:

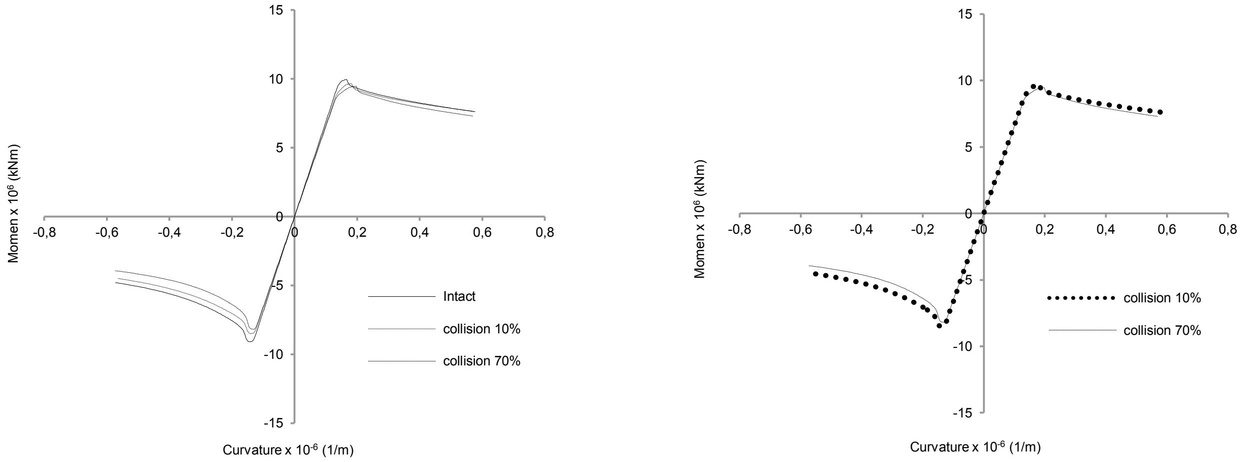


(a) 10 % damage (b) 70% damage

Figure 4. Collision damage of VLCC Tanker.

Results and Discussion

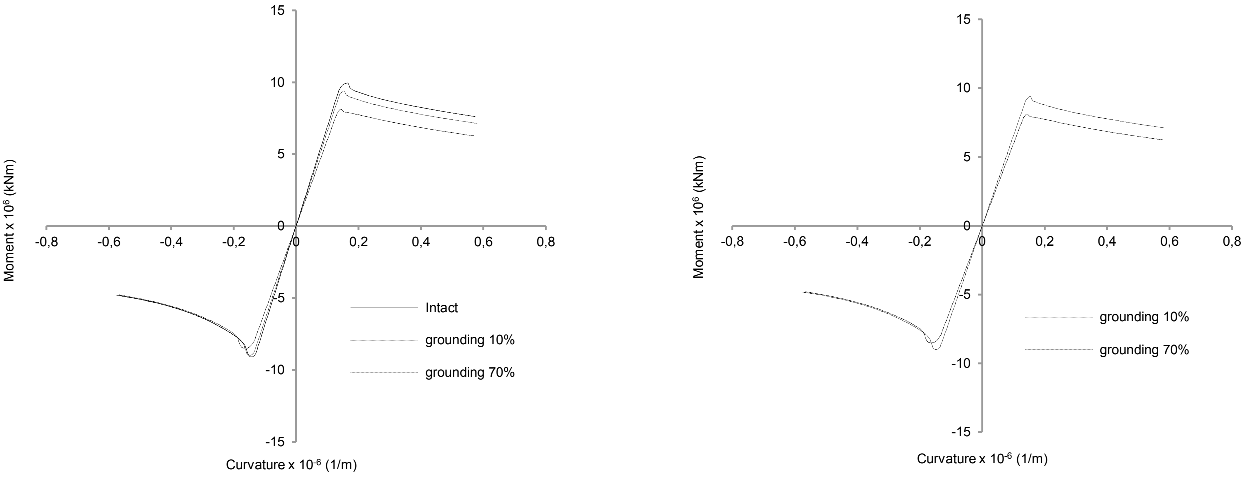
Collapse analysis of ship hull girder with grounding and collision damages are performed using the Smith's method. A VLCC of tanker is taken as the object of the analysis and subjected to longitudinal bending moment by taking the hogging and sagging condition into account. The ultimate strength for 10% and 70% of grounding damages are summarized as follows:



(a) Intact and damages (b) Damages only

Figure 5. Moment-curvature relationship.

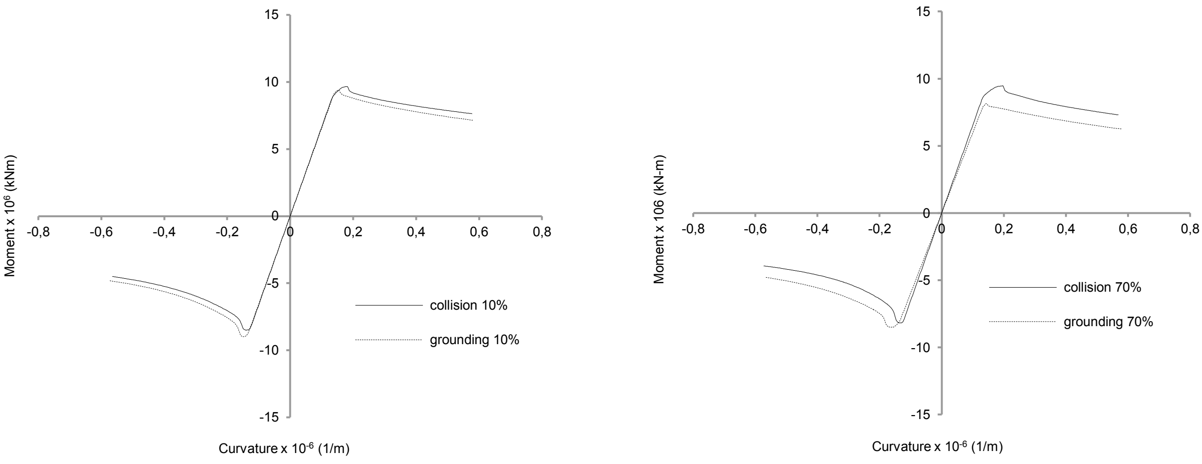
Figure 5 shows the comparison of the moment-curvature relationship of the ultimate strength for 10% and 70% collision damages. It is clear that the ultimate strength decreases not only hogging but also sagging conditions, when those compare to the intact one. The significant influence takes place on the post ultimate strength, particularly when the ship is under compression. This is because there is transversal damage extent of B/16 at the deck part.



(a) Intact and damages (b) Damages only

Figure 6. Moment-curvature relationship.

The comparison of the moment-curvature relationship of the ultimate strength for 10% and 70% grounding damages are shown in Fig. 6. When the grounding damage is considered, the significant different of the collapse behavior takes place on the hogging condition. It is known well that under hogging condition, bottom part is under compression and deck is under tension. In this regard, some of the elements at the bottom part lost their rigidity due to grounding damage. This is also due to the asymmetric position of the damage.



(a) 10% damages (b) 70% damages

Figure 7. Moment-curvature relationship.

The moment-curvature relationship obtained by analytical solution for 10% damage and 70% damages under hogging and sagging condition subjected to grounding and collision damages. It is observed that the ultimate strength for the collision damage is larger than grounding one under hogging condition. This is due to the transversal damage extent at the deck part since the deck part is under hogging condition. On the other hand, grounding gives larger ultimate strength compared to the collision, since grounding located at the asymmetric position of the bottom part. Similarly with the 70% damage both hogging and sagging condition.

Conclusions

Collapse analysis of ship hull girder with grounding and collision damages have been conducted using the Smith's method. The following conclusion of the collapse analysis of a VLCC of tanker are summarized :

1. It is clear that the ultimate strength decreases not only hogging but also sagging conditions when those are compared to the intact one. The significant influence takes place on the post ultimate strength, particularly when the ship is under compression.
2. It is observed that the ultimate strength for the collision damage is larger than grounding one under hogging condition. This is due to the transversal damage extent at the deck part since the deck part is under hogging condition. On the other hand, grounding gives larger ultimate strength compared to the collision, since grounding located at the asymmeric position of the bottom part.

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